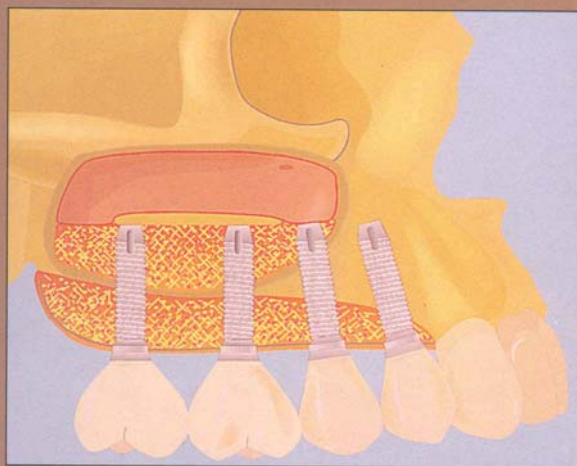
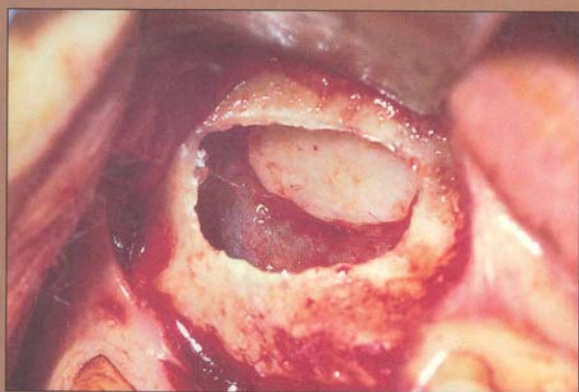


The Sinus Bone Graft



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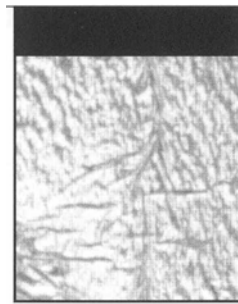
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The History of Maxillary Sinus Grafting

Philip J. Boyne, DMD, MS

Traditionally, the maxillary sinus has been an area that has been avoided by most dental procedures. In the past, general practitioners and oral and maxillofacial surgeons always avoided entering the maxillary sinus from the oral cavity unless they considered it to be absolutely necessary. Even otolaryngologists usually considered the undertaking of antrostomies only as part of more involved nasal sinus procedures. Thus, it is unusual that such an anatomic structure should now be entered almost routinely for sinus floor grafting to allow osseous fixation of metallic root-form implants.

Bone grafting of the maxillary sinus in cases of trauma, however, has been well established. Comminuted fractures involving the maxillae, orbital floor, lateral nasal wall, and maxillary alveolus are reduced by open reduction. Through either primary or secondary bone grafting, these bones have been completely restructured and rebuilt to their original anatomic conformation. The use of bone grafting of the maxillary sinus for prosthodontic reasons, however, has been very rare, and the application of such grafting procedures other than for osseous restoration after oncologic partial resection of the maxilla or after traumatic avulsion or comminution has been rarely reported in literature.

Early Bone-Grafting Procedures for Conventional Prostheses

The first use of bone grafting of the maxillary sinus to increase bony depth and bulk of osseous tissue for prosthodontic reasons was in the 1960s by Boyne.¹ Grafting of the maxillary sinus was used at that time to increase the bulk of bone for later maxillary posterior ridge reduction to obtain optimal prosthodontic interarch distance. Some patients presenting for conventional complete maxillary and mandibular prostheses had bulbous or enlarged tuberosities that were impinging on the interarch space making it impossible to construct complete mandibular and maxillary prostheses. Because the removal of bone from the mandible was not feasible, removal of bone from the maxillary tuberosity was the obvious option. However, some of these patients presented with large, pneumatized sinuses that would not permit the removal of bone to produce the necessary interarch accommodation. Therefore, construction of a functional prosthesis was extremely difficult or impossible.

To correct this condition of insufficient interarch space, a Caldwell-luc opening was made in the maxillary antrum, the sinus membrane was elevated, and then an autogenous particulate marrow cancellous bone (PMCB) graft was placed in the sinus floor. Approximately 3 months later, the bone of the tuberosity could be reduced, along with excess soft tissue, without the danger of the opening into the antrum, because additional osseous structure had been obtained by the

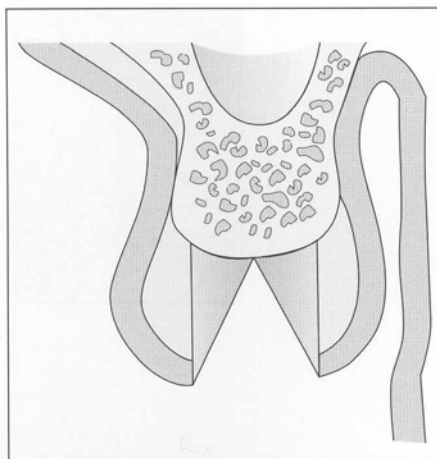


Fig 1-1 The soft tissue is reduced preparatory to reduction of the bone of a large maxillary tuberosity.

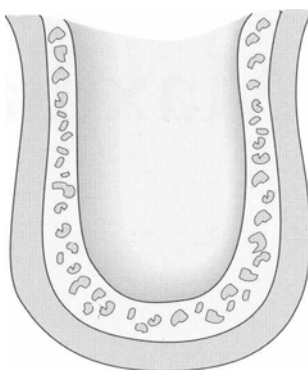


Fig 1-2 An enlarged posterior maxilla has a pneumatized antrum and insufficient bone to sustain osseous reduction of the tuberosity.

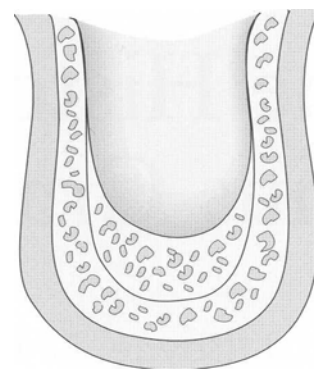


Fig 1-3 A sinus bone graft has been placed to increase the thickness of the sinus floor. The entire tuberosity can be reduced approximately 3 months after grafting to produce sufficient interarch space.

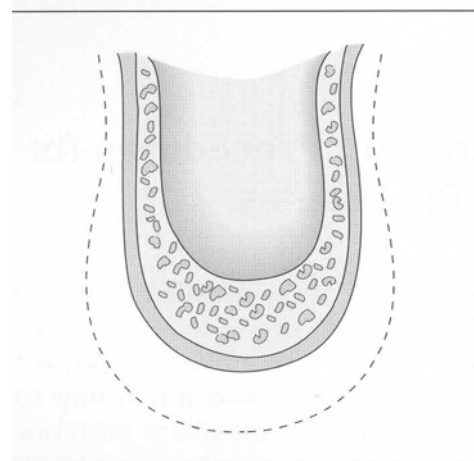


Fig 1-4 Three months after grafting, the posterior maxilla and tuberosity are surgically reduced to produce adequate interarch space (outer outline on the diagram).

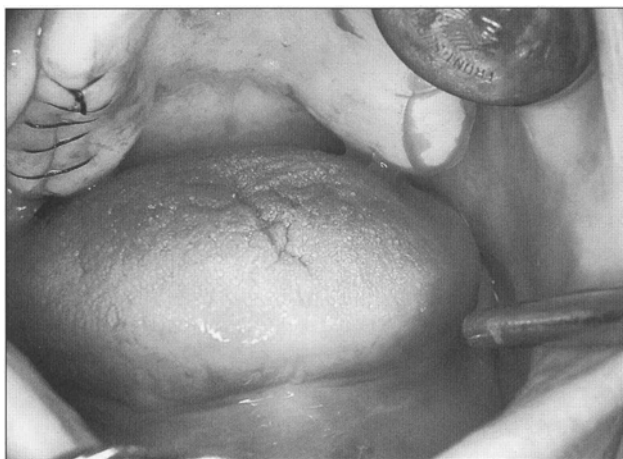


Fig 1-5 Reduction of the maxillary tuberosities after sufficient height of the sinus floor has been obtained by grafting. (The same type of high Caldwell-Luc approach for sinus grafting was used in the 1970s by Boyne and James² for placement of blade implants.)

previous grafting procedure. This unique procedure enabled many patients who otherwise would have been denied adequate reconstruction to have conventional prostheses (Figs 1-1 to 1-5).

Bone Grafting of the Maxillary Sinus for Metallic Implants

Blade implants

During the late 1970s, grafting of the maxillary sinus described for conventional prostheses was undertaken for patients who had large, pneumatized antra and needed blade implant placement to allow construction

of fixed, semifixed, or removable prostheses for edentulous areas of the posterior maxilla. Autogenous PMCB was usually used as the grafting material. After an appropriate postoperation period of approximately 3 months, the blade implant was placed. The blade implants were then used as abutments for removable or fixed prostheses. In 1980, Boyne and James² published the first report of the use of bone grafting to allow placement of metallic implants.

Prior to this, in clinical demonstrations, Tatum had lectured on the subject but had not reported results in the literature. It appears that during this time (1974 to 1979), more than one oral and maxillofacial surgeon was working in this field, investigating various types of procedures to obtain increased antral bone height for the reception of metallic implants.

Root-form implants

With the advent of titanium root-form implants, it became obvious that many possible posterior maxillary reception sites for implants were deficient in vertical bone height and width. The augmentation of the alveolar ridge itself was a possible method of correcting this deficit, but in many situations the antrum also required bone grafting. Various practitioners then undertook different surgical techniques to enter the antrum to elevate the sinus membrane and to place various types of bone grafts. Three major differences in technical approach to the surgical procedure were reported³:

1. The type of bone graft material utilized varied markedly with the individual practitioner or surgeon.³⁻⁵
2. The method of entering the antrum (antrostomy) and the anatomic site of the antrostomy varied with the surgeon utilizing the procedure.^{4,6}
3. The amount of elevation of the sinus membrane also varied markedly.⁶

In general, three anatomic locations were utilized to enter the antrum:

1. The classic superior position of the Caldwell-Luc opening, located just anterior to the zygomatic buttress.⁴
2. A midmaxillary entrance, between the level of the crest of the alveolar ridge and the level of the zygomatic buttress area.^{4,6}
3. A low position along the anterior surface of the maxilla, practically at the level of the existing alveolar ridge.^{6,7}

The third area became quite popular because it gave a quick access to the sinus floor and enabled the practitioner to make an antral window to impact the buccal osseous plate into the antrum, expeditiously implant the bone graft material, and close the incision. However, this particular entrance into the antrum poses a problem in that it makes an osseous opening in the maxillary sinus at a very anatomically dependent position. Should there be any infection, large hematoma, or preexisting sinus disease, the resulting drainage would collect in the area of the osteotomy and tend to produce an oroantral fistula. Thus the midposition antrostomy or the high classic Caldwell-Luc opening tended to be recommended by most oral and maxillofacial surgeons.⁵

Additionally, the use of the lateral cortical plate, which represented the window of the antrostomy, varied with the surgical technique. Many preferred to completely eliminate the bony "window" by using a bur to thin the cortical plate down to a paper-thin cortex and removing the thin bone carefully with a mosquito hemostat prior to elevation of the sinus membrane. Others

preferred to utilize the impacted cortical plate as a superior window, leaving it attached to the mucosa. Still others preferred to impact the cortical plate window and then remove it and replace it on the lateral surface as a graft at the end of the procedure. The theory behind this procedure was that the cortical plate would ensure that the antrostomy window would not completely heal without the replacement of the cortical plate. Surgical procedures have demonstrated, however, that following the placement of a compatible graft material in the antrum or the use of resorbable or nonresorbable membranes, the antrostomy window will heal with the apposition of bone without the use of the cortical bone window.^{8,9}

The amount of elevation of the sinus membrane also varied. Some practitioners used minimal elevation. Others preferred to elevate particularly from the medial or nasal walls of all of the sinus membrane, while others preferred to elevate only the sinus membrane from the lower half of the antral cavity. The advantage of membrane elevation is that if there is a laceration in the sinus membrane, the freeing up of the mucosa will allow the membrane to collapse over the lacerated portion of the soft tissue, which facilitates healing. If the membrane is not elevated, it tends to be taut, and the laceration or opening will tend to persist because of the tightness of the membrane in the area.

The results of these various types of graft procedures and types of bone graft materials were reported at a consensus conference on sinus grafting in 1996.³

Indications for the use of Graft Materials in the Antrum

One aspect of sinus grafting for the placement of rootform implants involves the possible appropriateness of grafting and the diagnosis of the need for grafting when implants are placed. It is generally conceded that residual bone in the alveolar ridge should exceed 4 to 5 mm if it is to effectively immobilize the implant while the sinus bone graft is maturing.³ There is a great deal of difference of opinion, however, as to the need for grafting if implants protrude into the antrum.⁸

Some believe that any protrusion of an implant into the antrum requires some sort of bone grafting, necessitating entrance into the antrum for surgical osseous reconstruction. Others believe that a certain amount of protrusion into the antrum by the root-form implant may be allowed without any additional grafting procedure, provided that the prosthodontic load on the implant is not inappropriate and is to be shared by other teeth or other implants.⁸

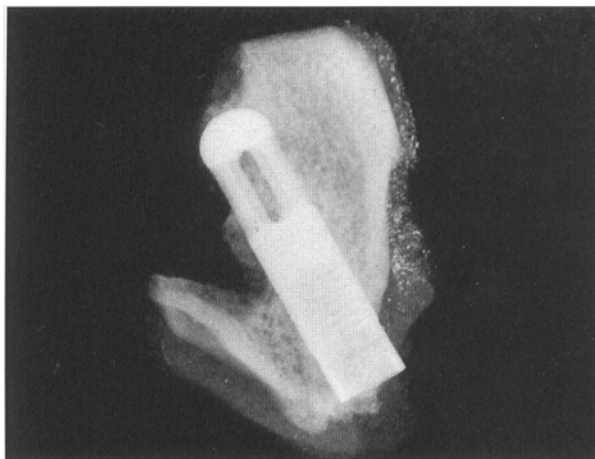


Fig 1-6 About 50% of the surface of an implant receiving no bone graft is covered with spontaneous bone repair. The rounded cylindrical surface of the implant is titanium plasma sprayed.



Fig 1- 7 New bone is present around the entire surface of an implant that did receive bone graft. (Specimen taken after 14 months of occlusal function.)

Work on rhesus monkeys (*Macaca fascicularis*) has shown that implants protruding up to 5 mm in the antrum without a graft can be subjected to more than 14 months of occlusal force and can function and perform as well as those implants that are grafted.⁸ The governing and defining factor appears to be distribution of the occlusal load among other implants or natural teeth and not the mere protrusion of the implant into the antrum. Implants protruding 5 mm into the antrum under these conditions were found to have more than half of their surface covered spontaneously by bone repair from the sinus floor in the absence of any bone graft⁴ (Figs 1-6 and 1-7). Thus, it would appear that the mere protrusion of an implant into the sinus floor is not in itself an indication of a need for bone grafting.

More importantly it would appear that the configuration of the implant itself is more important in defining the result of penetration of the sinus floor, because certain types of implants with sharp margins, openended apices, or deep-threaded configurations have exhibited in rhesus monkeys very little spontaneous bone regeneration. Under the same conditions, rounded cylindrical implants tend to invite the growth of bone from the sinus floor spontaneously over the surface, without any bone-grafting procedure.^s It was found that titanium plasma-sprayed cylindrical rounded implants protruding 2 to 3 mm into the antrum have complete spontaneous regeneration of bone over the surface

without a bone graft. The same type of implant protruding up to 5 mm tends to have a partial growth of bone toward the apex but not complete coverage by osseous repair.^s The same degree of sinus floor penetration by open-ended implants or deep-threaded implants produces little bone regeneration (Figs 1-8 and 1-9).

Edentulous Posterior Maxillary Areas

Sinus grafting and the placement of root-form implants has also led to review of the anatomic characteristics of resorption of the alveolar ridge following the loss of teeth. It has been observed that the edentulous areas of the posterior maxilla tend to lose bone buccally, so that the central portion of the residual resorbed ridge is more palatally displaced.⁹ The placement of implants in the midportion of the ridge in such patients often results in the apical end of the implant being positioned in the nasal wall of the antrum or in the nasal floor itself/ which has been shown by examination of cadaver material (Figs 1-10a and 1-10b). This observation is important, because it points out again the need for adhering to presurgical and pregrafting diagnostic criteria to determine the correct area to be grafted for maximal support of the implant system being used.

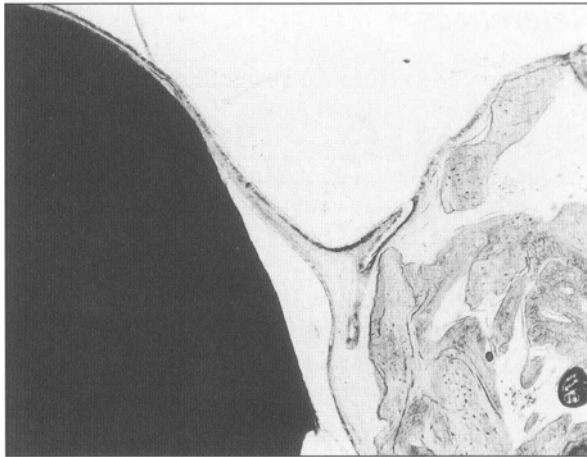


Fig 1.8 Microscopic view of an implant that did not receive a bone graft and was protruding 5 mm into the antrum. The area is now showing spontaneous growth of bone from the sinus floor, covering more than half of the implant surface. Thus, in many cases, the mere penetration of the antrum by an implant does not necessitate a bone graft. (Specimen taken after 14 months of function.)

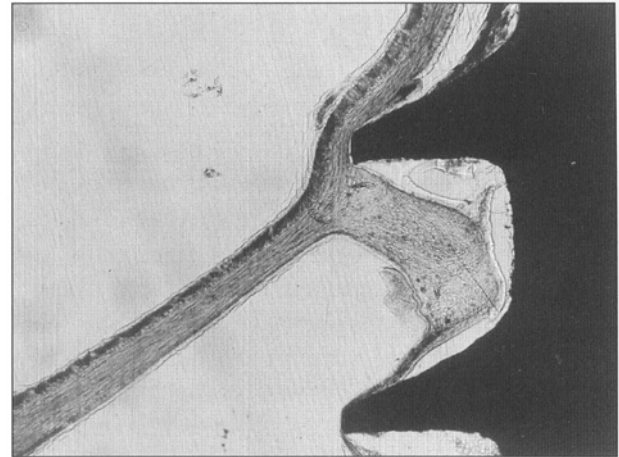


Fig 1.9 An implant with a different conformity and sharp surface angles has been placed to enter the sinus floor and protrude 5 mm. The bone does not tend to spontaneously regenerate over the penetrating implant. Only the sinus membrane is visible over the implant surface. (Specimen taken after 14 months of function.)

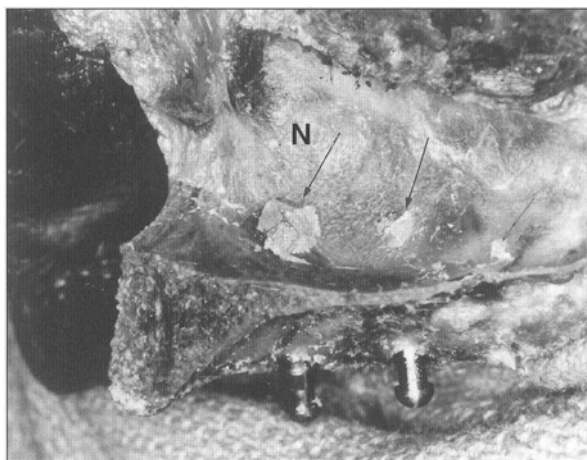


Fig I-IOa Apices of implants (*arrows*) placed in an edentulous posterior maxilla of a cadaver skull are appearing in the inferior meatus of the nose (N) rather than the maxillary sinus.

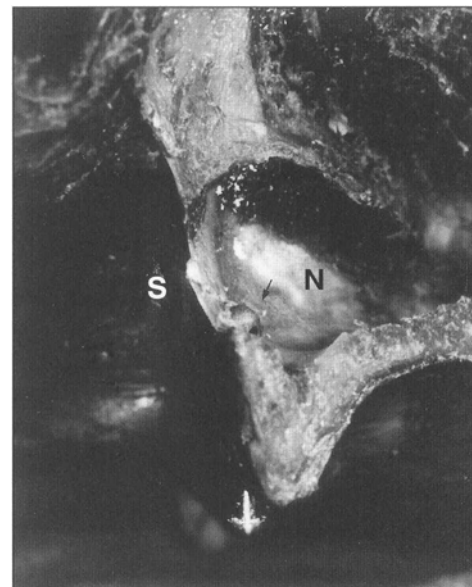


Fig I-IOb Implants placed on the crest of the alveolar ridge are penetrating (*arrow*) into the inferior meatus of the nose (N), despite the fact that the implants have been placed lateral to the ridge crest in an effort to produce an antral penetration. This indicates that with advancing atrophy, the maxilla resorbs from buccal to palatal, and thus the residual crest of the ridge "moves" palatally. Implants placed on the atrophic crest will, as a result, usually penetrate the nasal floor rather than the sinus floor (S).

Present and Future Aspects of Sinus Grafting

Research is now examining the use of bone graft inductor materials incorporated in suitable carriers and placed in the antrum to produce bone formation without the use of conventional bone-grafting materials (autogenous, allogeneic, or alloplastic). It has been shown that bone morphogenetic protein in an appropriate collagen carrier will regenerate bone in large discontinuity defects of the mandible/o in surgically created maxillary "cleft" defects,¹¹ and in the sinus floors of patients.¹² Current research is underway in a multicenter study utilizing bone morphogenetic protein in sinus grafting for the placement of implants in clinical patients¹² (see Chapter 12). Thus, the thrust of the future will be in the use of bone inductor materials.

The history of sinus bone grafting for prosthodontic reasons has been interesting and exciting. Future areas of research offer the opportunity for development of better methods of treating prosthodontic patients with maxillary deficiencies having a need for osseous reconstruction as part of their overall root-form implant-supported prosthodontic rehabilitation.

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Indications and Contraindications for Sinus Grafting

Joel L. Rosenlicht, DMD

The maxillary subantral augmentation procedure is a well-established technique for increasing bone volume in the deficient posterior maxilla.

As with any surgical procedure, knowledge and understanding of the indications and contra indications are vital. Understanding of the medical and surgical risk factors should always be paramount in the decision to proceed with surgery. Risks and benefits are also important and must be weighed along with those surgical risks that can be counted.

The maxilla presents with a variety of anatomic structures. Understanding the structures and their function is critical in performing sinus bone grafting.¹ These structures, such as the maxillary sinus, lateral nasal wall, pterygoid plates, associated vasculature, and teeth, are discussed in other chapters of this text.

The function of the maxillary sinus and the effect of sinus bone grafting have not been clearly identified in long-term studies. However, grafting does not appear to cause significant long-term negative changes in sinus function. Rosenlicht and Tarnow² described long-term, 2-year postoperative neuralgic changes to the maxilla. There have been various reports of graft infections, with subsequent erosion of bone and oroantral fistulas, lack of graft consolidation, and nonintegration of implants.

Indications for Maxillary Subantral Augmentation

Whether or not a sinus floor augmentation bone graft is indicated is a matter of clinical judgment by the surgeon. Both general factors, such as medical conditions, and local factors, such as periodontal disease and/or infection, can affect this decision. There are numerous procedures to increase the dimension of the posterior maxilla; onlay grafting, including lateral, buccal, and occlusal applications, has its indications, as does interpositional bone grafting.³ The following are some of the indications for sinus bone grafting:

1. Implant placement in areas of insufficient bone volume or decreased inter arch space
2. Oroantral fistula repair
3. Alveolar cleft reconstruction
4. Le Fort I downfracture with interpositional grafting
5. Cancer reconstruction for craniofacial prostheses

Guidelines to follow for sinus grafting for dental implants may also include the following:

1. Alveolar residual bone height of less than 10 mm
2. Less than 4 mm of residual bone width
3. No history of pathosis
4. No significant history of sinus disease
5. No anatomic limitations presented by anatomic structures or scarring after previous surgery

Contraindications to Maxillary Subantral Augmentation

General medical contraindications

1. Radiation treatment to the maxillary region
2. Sepsis
3. Severe medical fragility
4. Uncontrolled systemic disease
5. Excessive tobacco abuse
6. Excessive alcohol or substance abuse
7. Psychophobias

Local factors that may contraindicate subantral augmentation

1. Maxillary sinus infections (empyema)
2. Chronic sinusitis
3. Alveolar scar ablation (from previous surgical procedure)
4. Odontogenic infections
5. Inflammatory or pathologic lesions
6. Severe allergic rhinitis

Medical Considerations for Sinus Grafting

The surgeon also must understand that, for many patients who have negative medical factors or present a relative risk, consideration of the procedure may be warranted because of the benefits that can be gained. Such relative risks might include moderate smoking or alcohol use; well-controlled systemic disease (eg, diabetes mellitus or hypothyroidism); seasonal allergies or mild sinus congestion; and osteoporosis.

All patients who are to undergo sinus surgical procedures should have a thorough medical evaluation. The degree of surgery, type of surgery, type of anesthesia, and general health of the patient are all critical criteria to determine the patient's candidacy for the procedures. Many times this evaluation will alter the course of treatment and/or anesthetic plans as the underlying problems are found. The American Association of Oral and Maxillofacial Surgeons, in its

Parameters of Care Manual,⁶ indicates the standard of care for numerous planned surgical procedures involving anesthesia. These parameters should include the following:

1. Completion of an appropriate medical history questionnaire by the patient
2. A review of this form by the surgeon with the patients
3. Physical evaluation and appropriate pretreatment vital signs assessment
4. Medical consultation or laboratory testing as indicated before treatment
5. Nothing-by-mouth status for patients who are to receive intravenous sedation
6. Appropriate standards of care for anesthesia

Numerous medical, surgical, and pharmacologic advances now make it possible for patients with various medical conditions to seek implant reconstruction. It is imperative that the current medical and surgical needs of patients be integrated for optimal care. The medical conditions discussed in the following sections are but a few of the patient management challenges that exist.⁶ This chapter will only bring to light some of the medical-surgical management needs in a very broad manner, because close communication and collaboration with appropriate medical consultants may be necessary. Many dental patients seem to separate their dental needs from their medical conditions, believing

that dental procedures in some way are less important or present less risk. However, the success of dental procedures is related not only to the actual surgery but also to the patient's ability to heal and systemically respond to the goal of bone remodeling and implant integration. These events may take weeks, months, or years, depending on the staging and techniques used.

Patients taking medication for medical conditions need to be appraised for the effect of the drug on the surgery as well as the impact of the surgery on their medical condition.⁷

Anesthesia

Whenever surgical procedures are contemplated, the associated risk factors are both medical and surgical. It is necessary in implant dentistry, where most cases are of short duration and have minimal surgical trauma, to carefully assess patients for both these categories of risk. Most dental implant patients and those requiring sinus grafting present a very minor anesthetic risk because of the widespread use of regional and controlled inhalation and intravenous medications for pain control. That being the case, the most common pharmacologic agents used in the dental office to successfully control pain during sinus grafting are the following:

1. Local anesthesia with or without epinephrine
2. Nitrous oxide-oxygen inhalation
3. Oral diazepam (Valium), triazolam (Halcion), and other oral sedative medications
4. Intravenous diazepam, midazolam (Versed), fentanyl, thiopental (Pentothal), methohexital (Brevital), or others for sedative effects.

The anesthetic techniques used by the variety of specialists performing sinus grafting in implant dentistry appear to be based on the practitioner's experience and comfort level with a variety of anesthetic modalities. A local survey of general practitioners, periodontists, and oral surgeons indicated significant differences in the anesthetic techniques utilized during many dental procedures. For maxillary subantral augmentation, there appears to be a significant difference in the anesthetic techniques utilized, based on the practitioner's surgical and anesthetic expertise, education, and experience. Table 2-1 presents the results of a regional survey about anesthetic modalities utilized by practitioners who perform sinus-grafting techniques.

Medical risk factors

Without question, the type of anesthesia employed, the duration and complexity of the procedure, the expected wound response, and the general health of the patient are all necessary factors to be taken into consideration. The medical evaluation for the sinus graft or dental implant patient should be no different from the evaluation any patient receives for a surgical procedure. The complex medical problems of patients today demand an understanding of the physiologic, psychological, and pharmacologic effects of medications and surgery (Table 2-2). The medical risk factors presented by patients fall into numerous categories:

1. Cardiovascular disease
2. Pulmonary disease
3. Endocrine disorders
4. Renal disease
5. Psychologically compromising conditions
6. Immunocompromising conditions

Those surgical risk factors that need to be addressed are complicated by the patient's medical history. The degree of the surgery to be provided, the anatomy of the surgical area, the quality of the soft tissue, the blood supply, the potential provisionalization for eating, and the overlying trauma to surgical sites enter into medical management and decision to render care. The American Society of Anesthesiologists has classified the operative risks for patients:

Table 2-1 Anesthetic modalities used during sinusgrafting procedures

Type of anesthesia	GP	Perio	OS
Local	60%	40%	20%
Local/inhalation	35%	50%	30%
Supplement (oral, intravenous)	5%	10%	50%

GP = general practitioners; Perio = periodontists; as = oral surgeons.

- Class I: No organic, physiologic, biochemical, systemic, or psychiatric disturbance in a patient scheduled for a procedure involving a localized pathologic process (healthy patient)
- Class II: Mid-to-moderate systemic disease (eg, mild, well-controlled hypertension)
 - Class III: Severe systemic disturbance (eg, diabetes mellitus with vascular complications or severe heart disease)
- Class IV: Severe life-threatening systemic disorder (eg, severe renal failure or unstable angina)
- Class V: Moribund patient who is not expected to survive
- Class E (subclass): Emergency procedure (added to any of above)

Coronary disease

It is imperative that all patients be assessed for their cardiac and circulatory health. Myocardial infarction is the most common cause of perioperative death. Operative patients older than 30 years have approximately a 1.3% risk of having a myocardial event. This risk escalates to 10% in patients older than 40 years. Within the general population, the risk of infarction is less than 1%. Patients who have sustained a myocardial infarction have a significant chance of having a second infarction, depending on the time since the original cardiac event occurred. It has been estimated that, within 3 months postsurgery, there is a 30% chance of perioperative reinfarction; this risk decreases to 15% and then, after 6 months, to approximately 5% to 6%. Again, the degree of surgery and the type of anesthesia play a very important role in the potential for this to occur with dental alveolar surgery.⁹

Critical factors to be aware of in patients with a history of myocardial infarction are the degree of residual myocardial ischemia, ventricular inability, and ventricular function. It is imperative that the dental professional wait 6 months after infarction has occurred, understand current medication, and obtain medical clearance for the procedure. Close communication with the patient's physician is certainly recommended before any of the medical risks associated with these patients are incurred.¹⁰

Table 2-2 Stopping and restarting medications in the perioperative period

Medication	Recommendations	Comments
<i>Endocrinologic medications</i>		
Diabetes mellitus medications		
Insulin	Half dose, intermediate D5W about 2 mL/kg/hr, sliding scale	
Oral hypoglycemics	Discontinue 1-3 days preoperatively	Chlorpropamide is long-acting
<i>Corticosteroids</i>	Preoperative coverage	Risk of adrenal insufficiency
<i>Thyroid medications</i>		
Hypothyroidism	No need to delay urgent surgery L-thyroxine is long-acting	
Hyperthyroidism	Prepare with antithyroid drug, iodide, and/or beta-blocker	
<i>Estrogens/progestins</i>		For major jaw reconstruction only
Oral contraceptives	Stop 3 weeks preoperatively	
<i>Cardiac medications</i>		
Replacement	Consider deep-vein thrombosis prophylaxis	
Cardiac glycosides	May continue Limited use as congestive heart failure prophylaxis	
Antiarrhythmic agents	Continue unless toxicity Prophylactic lidocaine if history of ventricular tachycardia or complex ventricular premature contractions Continue digoxin for supraventricular tachyarrhythmias Continue beta-blockers unless contraindicated	
Nitrates	Continue	
Diuretics	See under <i>Antihypertensives</i>	
Calcium channel-blocking agents	Continue for coronary artery stenosis, severe coronary artery diseases, or coronary artery bypass graft	Risk of rebound coronary artery stenosis
<i>Antihypertensives</i>		
General	Search for nonessential causes (eg, pheochromocytoma)	Hypertension complicating anesthesia is a major independent risk factor for surgery
Diuretics	Consider discontinuation and fluid expansion 2 days preoperatively	Potential volume depletion and low potassium
Beta-blockers	Continue	Important risks of discontinuation syndrome
Clonidine	Continue	Important risks of discontinuation syndrome
Methyldopa	Continue	Long-acting effects
Reserpine	Continue	Long-acting effects
Prazosin	Continue	
Hydralazine	Continue	Caution with parenteral doses
Captopril	Continue	Monitor potassium
<i>Anticoagulants</i>	Depends on patient risk and surgical procedure	See text
<i>Aspirin</i>	Discontinue at least 7 days preoperatively	Potential bleeding and metabolic problems
<i>Nonsteroidal anti-inflammatory drugs</i>	Discontinue 3 days preoperatively	Check bleeding time
<i>Pulmonary medications</i>	Continue until surgery; resume postoperatively	
<i>Antiepileptic medications</i>	Continue if for grand mal seizures	Phenobarbital, phenytoin are relatively long-acting Primidone, mephobarbital, mephentyoin are short-acting; coverage needed Avoid intramuscular phenytoin
<i>Psychotropics</i>		
Antidepressants	Discontinue several days to 1 week preoperatively	Are long-acting; drug interactions; surgical risks
Tranquilizers	Taper and discontinue several days preoperatively	Infrequent surgical risks; taper because of withdrawal syndrome
Lithium	Taper and discontinue several days preoperatively	Potential perioperative risks

From Cygan R, Watzin H. Stopping and restarting medications in the perioperative period. *J Gen Intern Med* 1987;2:270.

Hypertension

Hypertension may be best described as a sustained elevated blood pressure. Patients who have stable diastolic pressure of less than 110 mm Hg and are without symptoms may require no presurgical treatment. It has been estimated that 25 % of the patients under medical control will become hypertensive during the anesthetic and surgical procedure. About 20% to 30% are at risk for hypotension.^{11,11} For patients who have diastolic pressure higher than 110 mm Hg, medical consultation is needed before any elective surgery is performed.

Cardiac

arrhythmia

The multiple arrhythmias experienced by patients are too extensive to be discussed thoroughly in this chapter. Any patient with a history of cardiac arrhythmia should be monitored during the procedure, and close communication with the patient's cardiologist is imperative if the patient's medications are to be adjusted or altered. Pacemakers are not a contraindication to surgery, nor do they indicate a need for bacterial endocarditis prophylaxis. Patients may be taking not only antiarrhythmic medication but also anticoagulants. The sudden onset of arrhythmia during surgery may be indicative of underlying cardiac events, such as impending myocardial infarction, hypotension, metabolic derangement, or hypoxia.

Vascular heart disease

Vascular heart disease may be associated with congestive heart failure and necessitate knowledge of the patient's cardiac output. In many cases, prophylaxis against subacute bacterial endocarditis will be required!³ (Tables 2-3 and 2-4).

According to the American Heart Association, conditions that require prophylaxis include:

1. Prosthetic valves
2. Previous history of subacute bacterial endocarditis
3. Congenital malformations
4. Rheumatic heart disease
5. Vascular surgery
6. Cardiomyopathy
7. Vascular disease with regurgitation

Conditions that do not require prophylaxis include:

1. Isolated nongrafted septal defects
2. Coronary bypass
3. Mitral valve prolapse without regurgitation
4. Functional murmurs
5. Cardiac pacemakers

Table 2-3 Recommended standard prophylactic regimen for dental, oral, or upper respiratory tract procedures in patients who are at risk* of bacterial endocarditis

<u>Drug</u>	<u>Dosing regimen</u>
<i>Standard regimen</i>	
Amoxicillin	3.0 g orally, 1 hour before procedure; then 1.5 g, 6 hours after initial dose
<i>Amoxicillin/penicillin-allergic patients</i>	
Erythromycin	Erythromycin ethylsuccinate, 800 mg, or erythromycin stearate, 1.0 g, orally 2 hours before procedure; then half dose, 6 hours after initial dose
or	
Clindamycin	300 mg orally, 1 hour before procedure; <u>then 150 mg, 6 hours after initial dose</u>

* Includes those patients with prosthetic heart valves and other high risk patients.

† Initial pediatric doses are as follows: amoxicillin, 50 mg/kg; erythromycin ethylsuccinate or erythromycin stearate, 20 mg/kg; and clindamycin, 10 g/kg. Follow-up doses should be half the initial dose. *Total pediatric dose should not exceed total adult dose.* The following weight ranges may also be used for the initial pediatric dose of amoxicillin: <15 kg, 750 mg; 15 to 30 kg, 1,500 mg; and > 30 kg, 3,000 mg (full adult dose).

From Dajani A, et al. Prevention of bacterial endocarditis. JAMA 1990;264:2422. Copyright 1990, American Medical Association.

Patients who are taking anticoagulating therapy present both surgical and medical risks. Those patients who are taking aspirin should be asked to refrain from taking it for 5 to 7 days prior to surgery. Patients taking sodium warfarin (Coumadin) also must be asked to stop taking the medication 3 to 5 days in advance. Presurgical verification of coagulation status, with prothrombin time, partial thromboplastin time, and bleeding time, is also an important consideration as are the discussion and communication with the patient's treating physician.

For any cardiac patient, obtaining medical clearance is in the best interest of the patient and an understanding of the pharmacologic interaction of anesthetic agents with the medication the patient is taking is imperative.

Diabetes mellitus

Patients with a history of diabetes must be evaluated very carefully for their blood sugar level and their ability to be stabilized. A history of diabetes may indicate some significant microvascular dysfunction that may result in impaired chemotaxis, impaired neutrophil function, and an anaerobic condition, especially for procedures requiring bone grafting and the placement

Table 2-4 Alternate prophylactic regimen for dental, oral, or upper respiratory tract procedures in patients who are at risk of bacterial endocarditis

Drug	Dosing regimen*
<i>Patients unable to take oral medications</i>	
Ampicillin	Intravenous or intramuscular administration of ampicillin, 2.0 g, 30 min before procedure; then intravenous or intramuscular administration of ampicillin, 1.0 g, or oral administration of amoxicillin, 1.5 g, 6 hours after initial dose
<i>Ampicillin/amoxicillin/penicillin-allergic patients unable to take oral medications</i>	
Clindamycin	Intravenous administration of 300 mg, 20 min before procedure; then intravenous or oral administration of 150 mg, 6 hours after initial dose
<i>Patients considered high risk and not candidates for standard regimen</i>	
Ampicillin, gentamicin and amoxicillin	Intravenous or intramuscular administration of ampicillin, 20.0 g, plus gentamicin, 1.5 mg/kg (not to exceed 80 mg), 30 minutes before procedure; then amoxicillin, 1.5 g, orally 6 hours after initial dose; alternatively, the parenteral regimen may be repeated 8 hours after initial dose
<i>Ampicillin/amoxicillin/penicillin-allergic patients considered at high risk</i>	
Vancomycin	Intravenous administration of 1.0 g over 1 hour, starting 1 hour before procedure; no repeated dose necessary

* Initial pediatric doses are as follows: amoxicillin, 50 mg/kg; clindamycin, 10 mg/kg; gentamicin, 2.0 mg/kg; and vancomycin, 20 mg/kg. Follow-up doses should be half the initial dose. *Total pediatric dose should not exceed total adult dose.* No initial dose is recommended in this table for amoxicillin (25 mg/kg is the follow-up dose).
From Dajani A, et al. Prevention of bacterial endocarditis. JAMA 1990;264:2422. Copyright 1990, American Medical Association.

of a variety of alloplastic, autogenous, or allogeneic bone-grafting products. The surgical stress experienced by these patients, compounded by the process and the release of regulatory hormones, may cause a variety of changes in the hyperglycemic and catabolic states of these patients.

Patients whose disease is controlled with oral medication may be treated differently from patients whose disease is controlled with insulin therapy. Orally controlled diabetics may be asked to discontinue their morning dose prior to the surgery and, with modification of their diet, have their medications readjusted following the surgical procedure.

Those patients who are insulin dependent should receive medical recommendation and clearance not only for the surgical procedure but also for the adjustment of their insulin medication. As a general rule, administering one half to one third of the usual dose of insulin the day of surgery, making sure the patient has between 50 and 100 mg of carbohydrate as a light breakfast, and performing the procedure with intravenous infiltration of dextrose 5% in water, allows some degree of control during the procedure. Following the procedure, assessment of blood sugars and modification of the patient's insulin dosage may be necessary to readjust the patient to a normal blood sugar level, depending on the patient's ability to rehydrate and masticate food.

For the patient with uncontrolled diabetes, the ability to heal and integrate grafts and implants is questionable. Patients with uncontrolled diabetes should not be considered candidates for sinus grafting or implants.

For those patients whose disease is under control, the adjunctive use of antibiotics, preoperatively and postoperatively, along with frequent assessment of blood sugar levels, may be recommended. Steroid therapy that would alter glucose levels should not be used.

Thyroid disorders

The surgical concerns for a patient with hypothyroidism are a decreased metabolic rate and significant potential for hypotension. The most common causes of hypothyroidism are Hashimoto's thyroiditis, idiopathic hypothyroidism, and surgical or radiation treatment to the thyroid. Patients with hyperthyroidism need to be carefully watched for thyroid storm, which may be life threatening. The most common causes of hyperthyroidism are Graves' disease, toxic nodular goiter, and subacute thyroiditis. Medical clearance and careful medical follow-up are highly recommended. These procedures, being elective, warrant careful medical management.

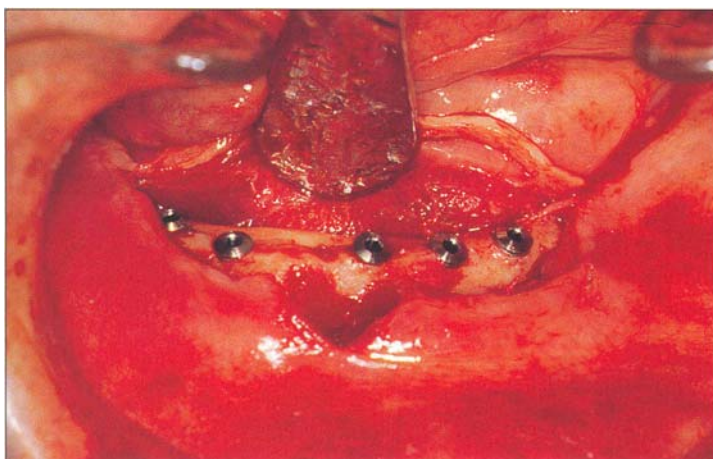


Fig 2-1a Immediate postoperative view of endosseous implants placed in the anterior mandible.



Fig 2-1b Healing after 3 weeks with 10 days of hyperbaric oxygen treatment.

Adrenal disorders

Although encountered less commonly than the aforementioned medical problems, adrenal disorders present significant concerns for elective treatment. The risks for patients with adrenal disorders include shock, dehydration, abdominal pain, nausea, and vomiting. All these events need to be carefully monitored in patients with any history of adrenal disease or patients whose disease is suppressed by steroid therapy.

It is most often recommended that steroid supplementation be utilized as a prophylactic regimen. The following are the most common prophylaxes:

1. Hydrocortisone sodium succinate, 100 mg intravenously, on call to operating room
2. Hydrocortisone, 50 mg intravenously, every 6 hours for the first 24 hours
3. Hydrocortisone, 25 mg intravenously, every 6 hours for the next 3 to 5 days

If the postoperative course is complicated by fever or hypotension, the hydrocortisone dose must be increased.

Immunocompromising conditions

Immunocompromised patients, depending on their reason for being immunocompromised, present numerous medical and surgical challenges. These patients often have significant hematologic concerns warranting close monitoring of blood count and coagulation times. Patients with previous history of transfusions, hemoglobinopathies, and white-cell and platelet abnormalities are common within this group. It is imperative that surgical procedures be performed when these patients are in their best state of health.

Patients who have received radiation treatment to the maxilla present the serious potential complication of radionecrosis along with delayed and poor healing of surgical sites. Radiation treatment to the maxilla might be considered a contraindication for the placement of maxillary implants as well as sinus grafting. From a surgical point of view, concerns go beyond excessive bruising and bleeding to include an increased incidence of infection, decreased maturation of grafted tissue, and, in general, extremely poor response to grafting procedures.

Careful timing of these procedures in conjunction with chemotherapy and medication must be considered. Long-term steroid therapy may have a significant negative effect on bone metabolism and healing. The use of steroids may also significantly affect the suppression of the adrenal gland within a very short period of time. Chemotherapeutic agents have a variety of metabolic and physiologic effects that must be understood and staged prior to surgical intervention. It is strongly recommended that all surgical treatment be coordinated with the patient and treating physicians.

Case 1. A 63-year-old man had a history of posterior pharyngeal sarcoma that was treated by excision and hemimandibulectomy followed by radiation therapy. Approximately 5 years following treatment, it was decided to place endosseous implants because the patient could not tolerate or wear any type of mandibular prosthesis. The placement of six implants in the anterior mandible was performed uneventfully (Fig 2-1a). However, following what appeared to be initially good healing, there was significant dehiscence and breakdown of the wound and an impending osteoradionecrosis became highly likely. The patient was immediately placed under hyperbaric oxygen therapy and subsequently two sessions of two atmospheres for 2 days (Fig 2-1b).

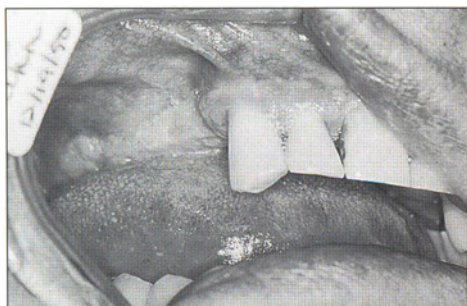


Fig 2-2a Preoperative view of the posterior maxilla.

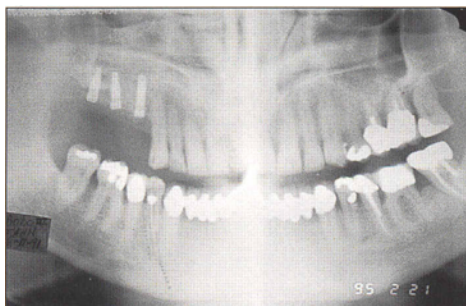


Fig 2-2b Placement of endosseous implants in the posterior maxilla in conjunction with maxillary subantral augmentation.

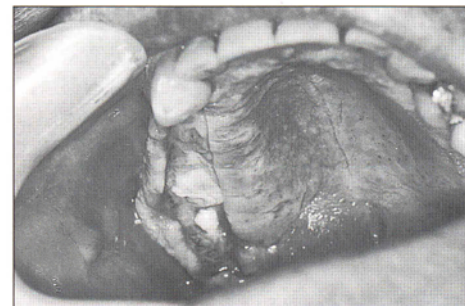


Fig 2-2c Two-week postoperative view showing total breakdown of wound margin.

Surgical risk factors

Smoking

Significant evidence is available that smoking inhibits wound healing and damages fibroblast precursors, producing ischemia and inhibiting epithelialization. It is recommended that, if a decision to proceed with surgery has been made, patients who are smokers refrain from smoking for 15 days prior to surgery (the time it takes nicotine to clear systemically) and 6 weeks after surgery. The complications of long-term smoking may significantly affect the outcome of surgery.¹⁴

Case 2. A 47-year-old man was edentulous in the maxillary right posterior region (Fig 2-2a). The ridge was severely atrophic, warranting the placement of endosseous implants in conjunction with maxillary subantral augmentation (Fig 2-2b). This patient smoked two to three packs of cigarettes a day and did not discontinue smoking prior to or following the surgical procedure. The patient's initial healing appeared unremarkable; however, after the sutures were removed during the second postoperative week, an entire dehiscence of the incision occurred, compromising and delaying the healing (Fig 2-2c).

Alcohol abuse

Alcohol abuse has a variety of systemic effects that not only affect the function of the liver but also may involve cardiomyopathies, anemias, cardiac problems, and neurologic events. Depending on the degree and amount of alcohol abuse, implant and sinus surgery are either relatively or absolutely contraindicated. Again, the surgical and medical factors are based on the degree of surgery required, the anatomy of the area, the quality of the soft tissue, the blood supply, and the needs for provisionalization.

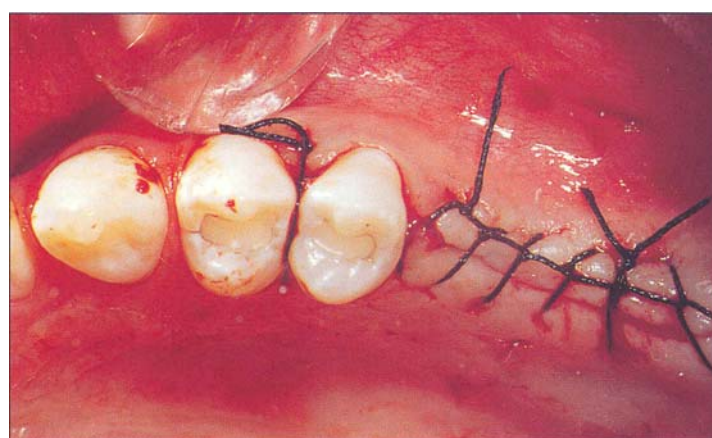


Fig 2-3 Nontension primary closure within minimal releasing incision to ensure adequate blood supply as well as enhance protection of graft and implants during healing.

Other surgical risk factors

When any patient is assessed for surgery, local considerations include bone quality and quantity, anatomic location of adjacent vital structures, concomitant need for presurgical grafting, the type of occlusion, and the ability to provide a provisional restoration for the patient. Further considerations are the selection of the appropriate graft material to be placed in the sinus as well as the systemic bone health of the patient. Parafunctional habits and provisionalization to prevent trauma to the area certainly need to be considered.

Implants often are placed concomitantly with sinus grafting, and, although many implants are within and under the gingival tissue, a degree of function on these surgical sites may cause enough micromovement or trauma to cause migration and/or nonintegration of the implants. During sinus grafting, the care and treatment of sinus perforation may have a significant effect on the viability of the graft. This aspect of treatment will be discussed further in other chapters.

The blood supply to the overlying soft tissue must also be considered. The judicious use of releasing incisions and the achievement of nontension primary closure to allow isolation of the graft and to maximize an environment to which the graft can remodel and mature are of significant importance (Fig 2-3). Accurate presurgical radiographic evaluation of anatomy as well as bone quality and quantity will help to prevent anatomic problems from becoming surgical risk factors.

It is always up to the surgeon to determine those patients who will be or will not be candidates for the operative procedures to be performed. Uncontrolled systemic disease, radiation treatment within 3 years, and untreated pathosis certainly fall within the range of contraindications to sinus grafting and implant procedures. Fortunately most dental implant treatment is elective, and medical necessity takes priority to ensure a patient's health as well as the success of grafting and implant procedures.¹⁵⁻¹⁷

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Vital Biomechanics of Bone-Grafted Dental Implants

Harold M. Frost, MD, DSc

This chapter concerns the dental and maxillofacial surgical problem of augmenting the human maxilla with bone grafts so it can support load-bearing dental implants. All operations have a ratio of successful to total procedures (S-T ratio). This is defined as the number of successful procedures (S) divided by the total number of procedures (T) (failed plus successful). An S-T ratio of 0.0 would mean 100% failed grafts. A ratio of 1.0 (unity) would mean 100% successes.

Insights in a new skeletal paradigm and some vital biomechanics might improve the S-T ratios of grafts and implants.¹⁻³ The insights came mainly from work on extremity bone problems, but it is argued that at least most of them should apply to analogous maxillofacial problems. Summarizing them involves some vocabulary and ideas taught in few dental or medical schools, so a glossary is appended. This chapter does not discuss graft and implant materials, biologic responses to them, or the relevant cell and molecular biology. It does discuss things that are not yet understood at the cellular- and molecular-biologic levels but that need such understanding.

Healing of the Graft

Infection excepted, such healing of a graft can take one of two broad routes.⁴⁻⁷ The graft may fail to incorporate and gradually disappear, or it can become a mechanically functioning part of the host bone. For the latter to happen, four overlapping healing phases must succeed,^{8,9} which usually takes longer in large grafts than in small grafts.

Incorporation

The hard and soft tissue host bed that surrounds the dead graft must be viable and have a good blood supply. Few grafts on nonvital host bone succeed. In the weeks after the grafting operation, the host bed produces new vessels, interstitial cells and materials, and new osteoblasts making woven bone, all of which embed the graft material to create the graft-woven bone complex.¹⁰ Cement lines must "weld" the woven bone to the graft material and the host bone to achieve mechanical support. This requirement limits the materials suitable for grafts. Autogenous cancellous bone is still the best available material.

These processes depend on many nonmechanical factors needed for cellular proliferation, migration, differentiation, function, gene expression, adhesion, and apoptosis.^{11,12} The factors come from bone matrix, local cells, and the blood. This incorporation phase can take more than 4 months. If it fails, the graft fails.

Replacement

Even while incorporation is finishing, basic multicellular unit (BMU) remodeling (described later) begins to replace the graft-woven bone complex with lamellar bone. Complete replacement can take more than 1 year. Remodeling usually slowly removes an incorporated graft that does not experience small mechanical strains, but, given suitable strains, it usually only replaces the graft-woven bone complex. If it fails to do that, the graft fails.

Modeling

Given somewhat larger strains, modeling begins to reshape the graft-woven bone complex internally and externally. It aligns the grain of any new lamellar bone to satisfy the local mechanical needs, and it aligns, shapes, and strengthens the complex's trabeculae and cortex to satisfy those needs.¹³ Here too, cement lines must weld the new lamellar bone to preexisting bone, graft material, and host bone. Completion of this phase can take more than 1 year and takes longer in older adults than in adolescents. If it does not happen, the graft fails.

Regional acceleratory phenomenon (RAP)

The trauma of the grafting procedure normally accelerates all regional tissue processes in the host bed.^{1,14,15} This reaction is the regional acceleratory phenomenon. It begins on the day of surgery and can last more than 2 years. The RAP accelerates all phases of bone graft healing. Failed RAPs decrease healing and resistance to infection, and can occur in regions of sensory denervation^{16,17} and in some chronic severe diseases (Type I diabetes, pulmonary insufficiency, congestive heart failure, hepatic cirrhosis). They can cause "biologic failures" of bone healing (often called *atrophic nonunions*).^{1,8,9,18} Some nonsteroidal anti-inflammatory agents can depress a RAP and retard the graft healing's replacement and modeling phases.^{19,20}

When successful, the four phases of graft healing create a host bone-graft bone complex that can function mechanically for life.

The emergence of vital biomechanics

In early views, the success of bone grafts depended mainly on osteoblasts and their regulation by nonmechanical factors, such as the following¹:

- | | |
|-------------------------|-------------------------------------|
| . Estrogen | . Mitogens |
| . Androgens | . Membrane pumps' . |
| . Growth hormone | Membrane receptors . |
| . Calcitonin | Apoptosis |
| . Somatomedins | . Other cytokines |
| . Insulin | . Paracrine effects |
| . Parathyroid hormone . | . Autocrine effects |
| Thyroxine | . Cell-cell interactions . |
| . Vitamin D | Amino acids |
| . D metabolites | . Lipids |
| . Other vitamins | . Gene expression |
| . Dietary calcium | . Drugs and other artificial agents |
| . Growth factors | |
| . Morphogens | |

However, it is now known that, in bone physiology, osteoblasts and osteoclasts are necessary *but not in control*. Other biologic factors mainly control the S- T ratio of bone grafts by controlling (1) the host bed's production of new capillaries and varied interstitial cells and materials, including osteoblasts,^{21,22} and (2) if, when, and where those phenomena (as well as replacement and modeling) occur, in addition to how much and for how long they take place.^{14,23} Problems with these matters cause far more problems with bone and graft healing than problems with osteoblasts or osteoclasts alone.

Clinical applications of the physiology summarized in this chapter are currently in flux in the general skeletal science, surgical, and medical communities. The understanding of vital biomechanics this chapter summarizes developed erratically. Up to 1990, it had few clear applications to the management of clinical problems. Many applications became apparent after 1990, but poor interdisciplinary communication still leaves many in skeletal science, surgery, and medicine unaware of or, perhaps, unsure about them. Ergo, most reviews explain bone physiology largely on nonmechanical grounds (biochemistry, genetics, endocrinology, cellular and molecular biology, etc.) and do not include vital biomechanics.

That does not suggest that nonmechanical factors are unimportant; they are clearly essential.²⁴ Equally clearly, however, they are not sufficient, and the equally essential vital biomechanics supplements the nonmechanical factors. In fact, the nonmechanical and vital biomechanical faces of skeletal physiology are essential to and dependent on each other. ^{15,25,26} Their relationships also reveal the indissoluble mutual dependence of cell and molecular biology on tissue- and organ-level physiology.²⁷⁻³⁰ Like other scientific controversies, this one will be resolved eventually.^{31,32}

Healing's histologic activities have been known for more than 100 years.^{33,34} Since 1960, most laboratory research on healing has focused on how nonmechanical agents affect it as a whole process and largely ignored how such agents affect the individual phases of healing. Between about 1964 and 1990, healing's four phases and some vital biomechanics involved in them became apparent and eventually, clarified.^{1,2,8,9,25,35-39}

Physical Determinants of Bone Strength

The strength of grafts and the host bone-graft bone complex depends on numerous factors.

Mass and architecture

Stiffness, ultimate strength, and yield point determine the strength of bone.^{1s} Lamellar bone excels woven bone in these respects. These mainly genetically determined "materials properties" vary little with age, sex, species, and most diseases, unlike the other physical determinants. A bone graft's strength also depends on how much bone lies in its cross section (the mass contribution). The more bone, and the more lamellar bone compared to woven bone, the stronger the graft. The shape and size of a mature graft, as well as the distribution of its cortical and trabecular bone (the architectural contribution), also affect its strength.

Making a bone graft stronger usually requires better architecture and more bone instead of better materials properties.

Microdamage

Microscopic fatigue damage, or micro damage, weakens bone without affecting its architecture or mass.^{35,36,40} Either as cracks and delamination visible in the light microscope or as earlier ultramicroscopic changes, micro damage can cause stress and spontaneous fractures of whole bones and trabeculae and loosening of load-bearing implants. Under parallel-grain loads that originally cause about 2,000 microstrain, normal lamellar bone endures about 10 million loading cycles before it breaks; however, under loads that originally cause approximately 4,000 microstrain, it can break in less than 20,000 cycles. As loads and strains only double in that range, microdamage increases more than 400 times.⁴¹

Repair by remodeling basic multicellular units, discussed later, can normally keep up with any microdamage caused by strains below about 2,000 microstrain. Larger strains can cause too much to repair, so microdamage accumulates to cause fatigue fractures.³⁶ Therefore that 2,000 to 4,000 microstrain region can define an operational *micro damage threshold* range (MESp), centered near 3,000 microstrain. For comparison, normal bone fractures at about 25,000 microstrain. (Discussion of a separate materials science threshold near the same strain range falls outside the concerns of this chapter; Patten et al⁴¹ have shown that one exists.)

After a grafting procedure, the maxillary host bone-graft bone complex should have reduced stiffness, more so early after the operation than later. This means that normal biting forces could cause strains in the bone supporting an implant to reach the microdamage threshold. The reduced stiffness of the complex would stem from an increased remodeling space because of increased turnover from the postoperative RAP; from incomplete replacement of the compliant initial graft

complex with the stiffer lamellar bone; from incomplete modeling of the graft; and from the reduced amounts of host bone that made the graft necessary.

Implants must provide enough surface touching bone so that *total loads* transferred from implant to bone keep *unit loads* on the bone below its microdamage threshold.^{1,42} Through 1997, no load-bearing implant on the market was intentionally designed to meet this requirement. This is surprising, because D. R. Carter noted that threshold's existence in 1984, and its role in implant design was noted in 1986¹⁴ and 1992.⁴² Nevertheless, the Branemark implants (Nobel Biocare) excelled in satisfying this condition.⁴³ Where too little host bone exists to satisfy this criterion, the grafts could increase the bone stock.

Bone cannot predict its future loads, so its biologic mechanisms adjust its strength to fit its past and ongoing loads in ways summarized in the next sections.

Vital- Biomechanical Determinants of Bone Strength

Bone modeling by drifts

Macromodeling

Global bone macromodeling (not osteoblasts alone) is the chief mechanism for increasing bone strength and mass; it rarely, if ever, decreases them^{1,25,44} (Fig 3-1). Bone formation and resorption drifts use osteoblasts and osteoclasts, respectively, to move bone surfaces in tissue space to determine a bone's shape, cross-sectional size, and strength. This tissue-level macromodeling (henceforth called *modeling*) works best during growth, and less well on adult cortical bone, but well on trabeculae for life. It is a slow process.⁴⁶ *Global* means averaged over a whole bone.

Where bone strains exceed a *modeling threshold* range (MESm) near 1,000 microstrain, modeling turns on to strengthen bone and reduce later strains toward the bottom of that range.⁴⁷⁻⁴⁹ Where strains stay below that threshold, mechanically controlled modeling turns off. Because the MESm lies below the micro damage threshold, this arrangement can keep bone strains comfortably below the micro damage threshold.^{1,36} Macromodeling determines where, when, and how much bone is added to meet local mechanical needs. Strains near and above the micro damage threshold usually stimulate woven bone formation drifts instead of lamellar bone drifts.^{37,49,50}

Macromodeling strengthens extremity bones and grafts to keep their strains from exceeding its threshold (MESm) and to keep strains below the microdamage

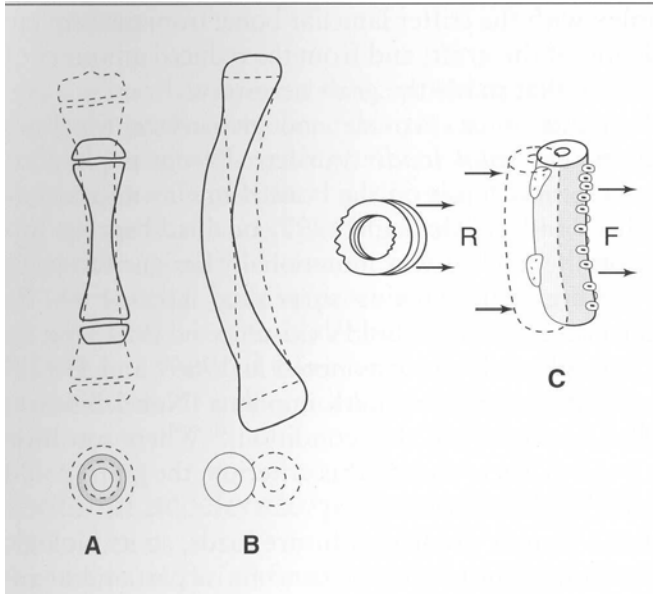


Fig 3-1 Bone modeling by drifts. (A) Infant's long bone with its original size and shape in solid lines. To keep this shape as it grows in length and diameter, its surfaces must move in tissue space as the dashed lines suggest. *Formation drifts* make and control new osteoblasts to build some surfaces up (as shown in Fig 3-4). Separate and independent *resorption drifts* make and control new osteoclasts to remove material from other surfaces. (B) A different drift pattern can correct the fracture malunion (solid line) in a child. The crosssectional view to the right shows the cortical-endosteal and the periosteal drifts that do that. (C) The drifts in (B) move the whole segment to the right (R = resorption; F = formation). Large forces from voluntary activities, such as in weight lifting, make modeling strengthen bone far better than do smaller voluntary forces, no matter how frequent, as in marathon running. Drifts can also thicken and strengthen trabeculae. They are created anew when and where they are needed, and they include capillaries, precursor and "supporting" cells, and some wandering cells. They are multicellular entities in the same sense as renal nephrons and hepatic lobules. The old idea that osteoblasts alone can add to and strengthen bone is no longer tenable; modeling drifts do it instead. (From Frost HM. Strain and other mechanical influences on bone strength and maintenance. CUfr Opin Orthop 1997;8:60-70. Reprinted with permission.)

threshold (otherwise all bones and grafts would fail). Micromodeling should do the same in maxillary grafts, which otherwise would all fail too.

Micromodeling

This cell-level activity determines what *kind* of tissue is formed, not where.⁵¹ In analogy, micromodeling determines the composition of bricks; then macromodeling builds arches, posts, and walls with them. Micromodeling determines if woven or lamellar bone forms in a given place. Normally it also aligns the "grain" of the lamellar bone parallel to the greatest strains of the bone it is formed on; grain, therefore, reveals the orientation of the larger strains and loads that the graft withstood while that bone was forming.³⁸ Woven bone can form where no bone existed before. Lamellar bone can only form on preexisting bone, either woven or lamellar. Strains of dead bone have no known effect on modeling, but they affect live bone attached to dead bone.

Bone remodeling by basic multicellular units

Global remodeling by BMUs (not osteoclasts alone) is the chief mechanism for reducing bone strength and mass. It rarely if ever increases them, and it also repairs microdamage,^{15,25,36} (Fig 3-2). In an activation _ resorp

tion _ formation sequence, a BMU replaces a small "packet" of old bone of either kind with new lamellar bone over 3 months or more. Also a slow process, continuing it for life requires continually creating new BMUs to replace completed ones, so those creations control bone turnover by remodeling.

Remodeling works in either of two modes, and a *re-modeling threshold* strain range (MESr), near 50 to 100 microstrain, helps to control the switching between them. Where strains stay below this threshold, remodeling BMUs make less bone than they resorb. This *disuse mode* removes bone, reduces bone strength and mass, and increases the remodeling space. Where strains exceed that threshold, resorption and formation by BMUs tend to equalize. This *conservation mode* conserves bone strength and mass, prevents an osteopenia or its progression, and usually reduces turnover and the remodeling space.⁴⁸

Basic multicellular units repair microdamage only in living bone.^{3s,52} Microdamage accumulates undetected and unrepaired in dead bone that carries loads (hence the subchQndral bone collapse in idiopathic aseptic necroses). Because remodeling BMUs replace the original graft with lamellar bone,^{8,9} agents that depress BMU creations ("antiremodeling agents") could impair the replacement. Some agents can also impair microdamage repair to loosen load-bearing implants or cause fatigue fractures of a bone or graft.^{14,53,54} Strains of dead bone have no known effect on remodeling. .

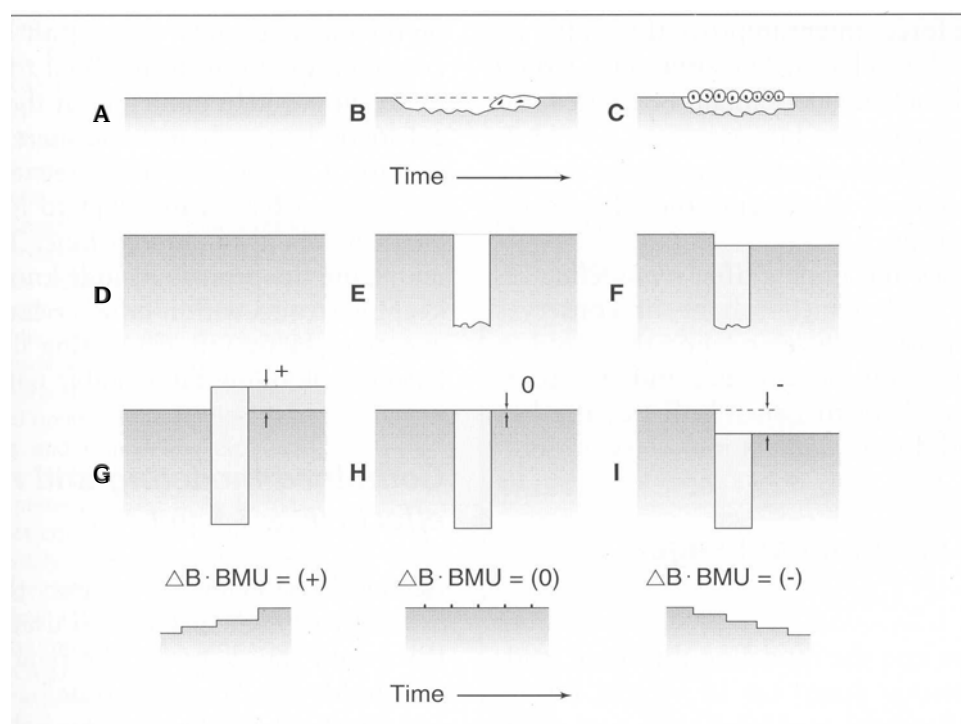


Fig 3-2 Bone-remodeling basic multicellular units (BMUs). (*Top row*) An activation event on a bone surface (A) causes a packet of bone resorption (B), and then replacement of the resorbed bone by osteoblasts (C). The BMU makes and controls the new osteoclasts and osteoblasts that do this. (*Second row*) Idealization of those activation events (D) maximizes the amounts of bone resorbed (E) and formed (F) by completed BMUs. (*Third row*) Basic multicellular unit graphs (after Frost). (G) Small excess of formation over resorption as, perhaps, on periosteal surfaces. (H) "Conservation mode," or equalized resorption and formation, as on haversian surfaces. (I) "Disuse mode," or deficit offormation, as on cortical-endosteal and trabecular surfaces. (*Bottom row*) These stair graphs (after pj Meunier) show the effects on the local bone balance and mass of a series of BMUs of the kind shown immediately above. Basic multicellular units are created anew when and where they are needed, and they include capillary, precursor, and "supporting" cells and some wandering cells. They are true multicellular entities in the same sense as renal nephrons and intestinal villi. The old idea that osteoclasts alone cause net bone losses is no longer tenable; basic multicellular units do it instead. (From Frost HM. Strain and other mechanical influences on bone strength and maintenance. *CUfr Opin Orthop* 1997;8:60-70. Reprinted with permission.)

Two-stage bone remodeling pattern

in disuse 1.25.49

When disuse begins, disuse-mode remodeling turns on. This increases bone loss, causes an osteopenia, and makes the bone less stiff. After an osteopenia develops, if the bone still carries some loads, remodeling changes to its conservation mode to minimize further bone loss. Ergo, the first stage causes the osteopenia and the second maintains it. Because rather small strains can turn the conservation mode on, suitably small biting forces that cause such strains in the host bone-graft bone complex might minimize bone loss during the replacement phase of a maxillary graft's healing. For more than two centuries, physicians knew that too much

strain (motion between the fracture fragments) impairs bone healing. Only recently did it become apparent that small strains not only improve that healing but also may be essential to it,ss-s8 because a total lack of strain can also impair healing.

For this chapter's concerns, as a bone-grafting procedure heals, the involved tissues are far less stiff than normal. For this reason, loads that would be normal for the undamaged structure can cause strains large enough to prevent healing. Yet small strains, perhaps in the 50 to 1,000 microstrain region, probably improve the healing. Nevertheless, very small loads, even those less than 1 % as large as normal peak biting forces, would cause such strains in healing fractures and grafts. In the early months after a maxillary grafting procedure, regularly

applied *small* biting forces might improve the graft's replacement and modeling phases, but large ones would be harmful. Such a beneficial force might be elicited, for example, by having the patient bite gently on a 1- or 2cm-thick soft sponge rubber mouthpiece several times a day. Although theoretical at present, the idea seems worth thought and study.

In extremity bones and bone grafts, remodeling replaces woven bone with lamellar bone, it conserves bone where strains exceed the remodeling threshold, it removes mechanically unneeded bone, and it repairs microdamage. Strains help to control all but the last function, and should do the same in maxillary grafts.

Hypervigorous mechanical usage

effects 1.40.48

By upshifting strains into the modeling threshold, sudden such hypervigorous usage (as in weight lifting, USA-style football, hard physical labor) can turn modeling on to thicken trabeculae and compact bone, while conservation-mode remodeling keeps the added bone. In chronic hypervigorous usage, bone strength would have increased enough to fit the increased loads, so in such adults modeling should turn off, bone strength and mass should plateau at higher levels, and conservation-mode remodeling should continue and keep the previously added bone. All those things do happen.^{59,60}

Modeling's responses to hypervigorous mechanical usage strengthen extremity bones and bone grafts to satisfy the loads on them (otherwise all bones and grafts would fail). These responses should do the same for maxillary grafts.

Adaptational lag

As bone loads steadily increase in children, the increases in bone strength provided by the sluggish, "error-driven" bone modeling lag behind the increasing needs. This lets strains exceed modeling's threshold and keep modeling on during growth. In most young adults, bone loads plateau, so bone's adaptations in strength could finally "catch up," turn modeling off, and reach a plateau. These are plausible reasons why extremity bone strains during growth do exceed those in adults, why modeling does turn off in young adults, and why their bone strength and mass do reach a plateau. The largest long-bone strains from voluntary efforts range between 2,000 and 4,000 microstrain in most growing subjects, but between 800 and 1,300 microstrain in most adults.^{40.48, so, 63-65}

Those properties should apply to load-bearing maxillary bone grafts too. If so, suitable biting forces

on the maxillary host bone-graft bone complex that increase gradually from minimal to normal over 2 years or so should help modeling fit the graft to its mechanical loads better than if the increases peaked in a few months. Clinical experience seems to support this idea.

Normal bone can adapt to nearly any mechanical challenge *if given enough time*. The tricks involved in managing the process include knowing what is enough, keeping strains within bone's relatively narrow comfort zone (see below), and resisting ill-conceived efforts to hasten a plodding but capable nature.

Combined modeling and remodeling effects (Figs 3-3 and 3-4)

Accumulated evidence suggests that in bones adapted normally to their mechanical usage, strains everywhere (E) would stay between the remodeling and modeling thresholds (the "comfort zone"), below the microdamage threshold (MESp), and far below the fracture strain (Fx). That relationship may exist in the extremity bones of all mammals, amphibians, birds, and reptiles of both sexes, so it could apply to maxillary bone grafts too. If so, it would define an aim of a successful graft, and a vital biomechanical criterion it must satisfy in order to succeed:

$$MESr \dots < \dots E \dots < \dots MESm \ll MESp \ll Fx$$

/adapted state/

The longitudinal tension and compression strain values cited in this chapter need more study, and shear and strain gradients, rates, frequencies, strain energy density, and other factors may also help to control a bone's adaptations to its mechanical usage. Until those matters are resolved, longitudinal strains can provide useful indices of such things, as well as reliable evidence of a bone's or graft's loads. Where this chapter mentions strain as an influence on a biologic activity, the idea "or equivalent stimulus" is always understood. Measuring strains in healing sinus grafts would be hard; finite-element modeling might prove useful in trying to estimate them.

Strain "Windows"

Both normal and healing bone can function in three broad strain windows, and provisional strain values can illustrate the idea (see Fig 3-3).^{1,67} Where strains (E) stay too small, bone is removed (the disuse window: $E < \text{about } 50 \text{ to } 100 \text{ microstrain}$). In a somewhat larger, narrow window, or comfort zone, bone strength is maintained or even increased (the adapted and mild

Fig 3-3 Combined modeling and remodeling effects on bone strength and mass. The horizontal line at the bottom suggests typical peak bone strains, from 0 on the left to the fracture strain (near 25,000 microstrain) on the right (Fx), plus the locations of the remodeling (MESr), modeling (MESm), and micro damage thresholds (MESp). The horizontal axis represents no net gains or losses of bone strength or mass. The dotted line curve suggests how remodeling responses to bone strains remove and weaken bone where strains stay below the MESr range, but otherwise tend to keep bone and its strength. The middle dashed line curve suggests how modeling responses to bone strains begin to increase bone strength where strains enter or exceed the MESm range. The solid outlines suggest the combined effects of modeling and remodeling on bone strength. At and beyond the MESp range, woven bone formation drifts usually replace lamellar bone formation drifts. In the nearly flat comfort zone or adapted window (AW), as in normally adapted adults, bone strength and mass change little as typical strains change. (OW) Disuse window; (MOW) mildly overload window as in growing mammals; (POW) pathologic overload window. The increasing body weight and muscle loads on children's bones can upshift some bone strains above the MESm range, to turn on modeling. Because these seem to be fundamental properties of living extremity bones, it can be inferred that this would be analogous to the healing of maxillary bone grafts. (From Frost HM. Strain and other mechanical influences on bone strength and maintenance. *Curr Opin Orthop* 1997;8:60-70. Reprinted with permission.)

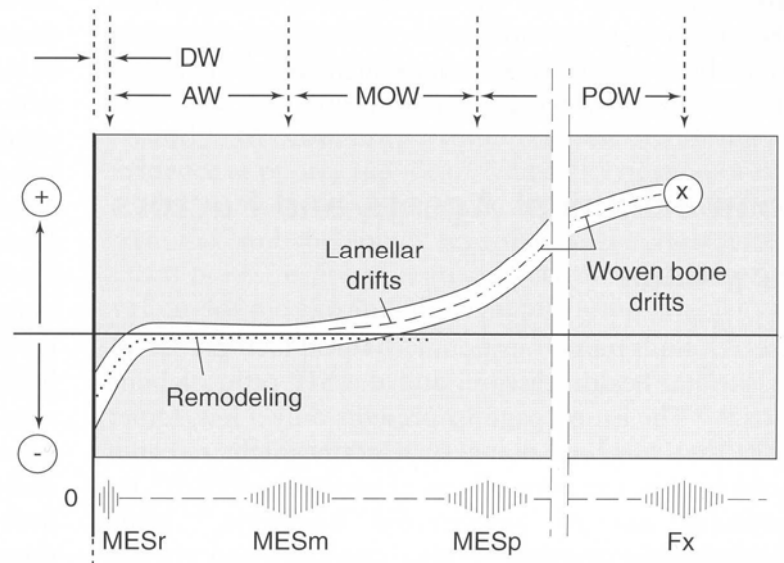


Fig 3-4 Tetracycline bone labeling. Ultraviolet fluorescence microscopy of an undecalcified cross section of the middle third of the left seventh rib. The patient was an adolescent girl who took tetracycline antibiotics for respiratory infections on three occasions before a thoracotomy for cardiac surgery provided this sample. This is the cutaneous cortex of the rib as viewed from the front of the patient, so its cutaneous-side periosteal surface lies on the right and the marrow cavity to the left. Tetracyclines deposit where new bone mineralizes. They are fluorescent under ultraviolet or blue light, so they provide a bone tissue time marker suitable for use in humans and animals. The three long, curved vertical bright lines to the right reveal tetracycline deposited on three occasions in a periosteal formation drift of lamellar bone. Its additions of new layers of bone gradually moved this periosteal surface to the reader's right in tissue space (this is normal in this part of this rib during growth). Knowing the time intervals between those "labels," one can measure the rate of bone formation by this modeling drift and its osteoblasts. In life, a companion resorption drift acted on the left (marrow cavity side) of this cortex, so this whole cortex drifted to the reader's right. The situation corresponds exactly to the cortical drifts shown in the right hand cortex in Fig 3-1 (C). The shorter curved lines inside the cortex are labels deposited in secondary osteons that were being formed when the labels in the formation drifts were deposited. Basic multicellular units made these osteons. They are elongated cylinders, parallel to the bone's length, seen in cross section here. The labeled osteons formed some time before the surgery at which this bone was resected, and newer ones partly replaced most of them. That explains the broken arcs. Because of the above drift pattern, the left half of this cortex is older than the right half. This helps to explain why the left half contains more secondary osteons; it had more time to accumulate them. The white curlicue in the marrow space in the lower part of the figure is a stray cotton fiber caught in the mounting medium. (Original magnification x 10.)



overload windows: $E > \text{about } 50 \text{ to } 100 \text{ to about } < 2,000$ microstrain). Under even larger strains, bone and its healing can both break down (the wide pathologic overload window: $E \text{ } 3,000 \text{ to } 25,000$ microstrain). This matter's potential uses in reconstructive bone procedures mean it needs more study. Also, surgeons might benefit by trying to think about such things in strainstiffness instead of stress-strength terms.

Nonmechanical Agents and Factors *The positive*

Research finds numerous nonmechanical factors that affect skeletal health, disease, and the S- T ratio of bone grafts.⁶⁸⁻⁷⁰ The list on page 18 presents only a few. Other things that surgeons doing such grafts might research would include the bone effects of prostaglandins,^{71,72} intermittent use of parathyroid hormone,⁷³ bone morphogenetic protein/^{4,75} other cytokines and growth factors/^{8,76} electrical current and external capacitive fields,^{n,78} and ultrasound treatment/⁹ Whether those things also accelerate bone graft healing and its modeling phase remains uncertain.

Pharmaceuticals

Excepting infection, increasing the S- T ratio for the incorporation phase of graft healing should depend heavily on nonmechanical factors that help in cellular proliferation, migration, differentiation, and function, including for osteoblasts. This should involve varied growth factors, agents that affect gene expression, cellular adhesion, cellular-intercellular matrix interactions, apoptosis, and other things. This problem should fall mainly in the domain of cell and molecular biology (but not exclusively), and provide an attractive target for "designer" drugs.⁸⁰

Both strains and nonmechanical agents control the replacement and modeling activities,^{8,9} so even in completely unloaded grafts some replacement and modeling occur while the remodeling mechanism proceeds to remove the entire graft. But both mechanisms provide essential mechanical functions in graft healing, and they depend on the graft's strains (or equivalents) to guide and determine the end points of those functions in time and space.⁸¹ This means agents that increase the responsiveness of modeling and BMU-based remodeling to strains might enhance those functions and increase the S-T ratio for these grafts.

Some hormones (growth hormone or a somatomedin?) might have such effects and help to explain why the S- T ratio in adolescents exceeds that in aged adults, in whom the hormone is usually less effective.⁸² As other examples, intermittent administration of parathyroid hormone can create new formation drifts of lamellar bone/^{3,83} while some prostaglandins can stimulate woven bone formation.^{72,84} This suggests such agents might enhance the modeling phase of graft healing. These problems would fall in both the vital-biomechanics I and cellular- and molecular-biologic domains. Little research has concerned them so far.

Timing the administration of such agents could be important.^{1,8,9,85} For example, agents that improve cellular proliferation and differentiation should be most helpful early in the incorporation phase, but less so near its end or in the replacement and modeling phases. Agents that enhance the responsiveness of modeling and remodeling to mechanical strains should provide little help early in the incorporation phase, because those two activities would not begin working then. Such agents should work better after the replacement and modeling phases of healing begin.

The negative

The causes of most failed RAPs remain enigmatic. Besides excessive strains, malnutrition and osteomalacia can impair all phases of bone graft healing. Other things that often impair it include severe cardiac, hepatic, renal, and pulmonary failure, diabetes, and osteopetrosis.⁸⁶ In many or most aging adults, a gradual decline in the responsiveness of bone's biologic mechanisms to appropriate stimuli seems to occur.^{10,87-89} This can adversely affect bone graft successes. Until agents that can correct such declines become available, surgeons and patients must learn to live with and try to allow for them.

Agents that can impair the remodeling and modeling a graft needs to succeed include local x-radiation/^o many bisphosphonates,^{s3} some drugs used to treat rheumatoid arthritis and malignancies, some used to minimize organ transplant rejections/¹ and some nonsteroidal anti-inflammatory drugs.^{2o,92}

Conclusion

The biologic mechanisms that model and remodel bone and that heal fractures and bone grafts need nonmechanical factors in order to work properly. However, mechanical factors guide the biologic mechanisms in time and anatomic space. The nonmechanical factors cannot provide that guidance. They can help or hinder its effects but cannot replace them (otherwise nonmechanical agents could normalize bone strength and mass in congenitally paralyzed limbs). Although knowledge of the cellular- and molecular-biologic factors involved in bone physiology and healing has increased dramatically, at present how those factors affect the responses of bone's biologic systems to strain and other mechanical factors remains enigmatic. Accordingly, future research must study these phenomena.

This chapter extrapolated to facial bone problems some physiology and experience drawn largely from extremity bone problems and studies. Clinical evidence strongly suggests that these extrapolations are valid. Nevertheless, facial bones and their investing soft tissues have a somewhat different embryonic origin than extremity bones, so in principle different gene expression patterns might make them respond somewhat differently to common stimuli. Some experimental evidence supports the idea.⁹³ Clinical evidence of it includes some differences in ligament affections in extremities and the spine⁹⁴ and the greater resistance of facial bones to postoperative infections. Therefore, the validity of the extrapolations made in this chapter must be verified.

- Glossary

bone "mass": The amount of bone tissue, often estimated by absorptiometry, preferably viewed as a volume minus the marrow cavity. It does not mean *gravimetric mass*, as used in physics. It can provide an unreliable index of bone strength because it does not account for the contribution of bone architecture to that strength.⁹⁵ In this chapter, *mass* refers to its use in absorptiometry.

BMU: Basic multicellular unit of bone remodeling. In approximately 4 months, and in a biologically coupled *activation – resorption – formation* (ARF) sequence, it turns over about 0.05 mm³ of bone in humans. When it makes less bone than it resorbs (its disuse mode), this tends to remove bone, usually next to marrow. Adult humans may create about 3 million new BMUs annually and about a million may function at any moment in the whole skeleton.¹

disuse: When typical peak bone strains downshift into the remodeling threshold region shown in Fig 3-3, for bone that would represent disuse and signal its existence, no matter how small or big the bone or bone graft. In such situations disuse-mode remodeling usually turns on to remove local bone. For a bone, disuse would be the relationship between the bone's strength and its usual loads. The resulting strains and the remodeling threshold would provide the criteria that recognize disuse. Very small loads can cause strains in that threshold region in a healing bone graft.

drift: See *modeling*.

MESm: Minimum effective strain range (or equivalent stimulus) for switching on mechanically controlled bone modeling drifts.^{1,47} An operational concept, the center of this genetically determined "modeling threshold" proba-

bly lies near 1,000 microstrain in most adults (equivalent to about 20 MPa), which could be viewed as its set point. Its value currently causes some debate.³⁶ Nonmechanical agents, drugs, disease, age, race, and species might modify its value.

MESp: Minimum effective strain range for bone's operational micro damage threshold. Under parallel-grain loading it should center near 3,000 microstrain (equivalent to about 60 MPa). Its value for across-grain loading remains unknown at present.^{1,36,41}

MESr: Minimum effective strain range (or equivalent stimulus) for mechanically controlled BMU-based remodeling.⁴⁰ Above it conservation-mode remodeling turns on to prevent net bone loss. Where strains stay below the MESr, disuse-mode remodeling turns on to cause net bone loss. Another operational concept, the center of this genetically determined threshold range would lie near 50 to 100 microstrain (equivalent to about 2 MPa), which could be viewed as its set point.^{2,38} Nonmechanical agents, drugs, disease, age, race, and species might modify its value.

modeling: Producing functionally purposeful sizes and shapes to skeletal organs. Mostly independent resorption and formation modeling drifts do it in bones and bone grafts. Modeling drifts mainly determine outside bone diameter, cortical thickness, and the upper limit of bone strength.²⁵ Remodeling determines the lower limit of bone strength.

osteopenia: Less bone than usual for most healthy people of the same age, height, sex, and race. Its definition still involves problems and opinions this chapter does not discuss.

- Glossary (coni.)

remodeling: Turnover of bone in small packets by basic multicellular units. Literature published before 1964 did not distinguish between modeling and remodeling and lumped them together as remodeling. Some authors still do that, which can be confusing. However, while drifts and BMUs create and use what seem to be the same kinds of osteoblasts and osteoclasts to do their work,⁴⁹ in different parts of the same bone at the same time the osteoblasts and osteoclasts in drifts and BMUs can act and respond differently and even oppositely to many influences.⁴⁹ In remodeling's disuse mode, BMU creations increase and completed BMUs make less bone than they resorb. In its conservation mode, BMU creations usually decrease and resorption and formation in completed BMUs tend to equalize.

remodeling space: Each BMU makes a temporary hole in bone or on a bone surface. The sum of all such holes equals the remodeling space, which can vary from about 3% to occasionally more than 30% of a bone's volume.⁹⁶ Due to surface-to-volume ratio effects, its value in trabecular bone usually exceeds the value in compact bone.

resorption: Different meanings of this term in the literature cause some confusion. Some authors use it to mean net bone loss, and in that sense discuss "antiresorption agents."²⁷ Others use it to mean bone resorption by osteoclasts, and refer to net losses of bone as such and separately. In this chapter, it means resorption by osteoclasts.^{1,2s} In that sense few true antiresorption agents exist, and they do not include estrogen or presently known and studied bisphosphonates, which instead are "antiremodeling agents" that decrease BMU creations. Because of the ARF sequence, this reduces global resorption first, and then formation, and both about equally.^{97,98} This could impair the replacement phase of bone graft healing, and might impair micro damage repair too, as some bisphosphonates do. Infection and neoplasm excepted, where a bone mass increases, modeling did it, not osteoblasts alone; where a bone mass decreases, disuse-mode remodeling did it, not osteoclasts alone.

strain: The deformation or change in dimensions and/or shape caused by a load on any structure or structural material. Special gauges can measure bone strains in the laboratory and in vivo. Loads always cause strains, even if

very small ones. In biomechanics strain is often expressed in microstrain units, where 1,000 microstrain in compression would shorten a bone by 0.1 % of its original length, 10,000 microstrain would shorten it by 1 % of that length, and 100,000 microstrain would shorten it by 10% of that length (and break it).⁴¹

stress: The elastic resistance of the intermolecular bonds in a material to being stretched by strains. Loads cause strains, which then cause stresses. Three principal strains and stresses include tension, compression, and shear. Stress cannot be measured directly but must be calculated from other information that often includes strain. The stress-strain curve of bone is not linear. The material is stiffer at small loads and strains than at large ones.

ultimate strength: The load or strain that, when applied once, usually fractures a bone. The fracture strength of normal lamellar bone is about 25,000 microstrain (CY about 0.3), which corresponds to a change in length of 2.5%, ie, from 100.0% to 97.5% of its original length under compression or to 102.5% of it under tension. That fracture strain corresponds to an ultimate or fracture stress of about 17,000 psi or about 120 MPa.¹⁵

unit load: The part of the total load on a bone carried by, say, 1 mm², 1 cm², or 1 inch² of its cross section or surface. It would cause corresponding principal strains and stresses. The unit load (w) equals the total load (W) divided by the cross section area (A) of the bone carrying it ($w = W/A$). The unit compression load usually equals the unit compression stress. In ordinary discourse, people often equate them, which can lead to the false idea that stress causes strain.

vital biomechanics: A sub field of general biomechanics that concerns how and why biologic mechanisms respond to mechanical usage and loads, and other physical stimuli, to adapt structural tissues and organs to their usual mechanical usage to make them mechanically competent and then keep them so for life.

woven bone: Also known as *primary bone*, *primitive bone*, and *reactive bone*. At the tissue level, woven bone lacks the "grain" that characterizes lamellar bone. In the body, if it carries no load, it is slowly removed. If it does carry loads, lamellar bone slowly replaces it.

Anatomic and Physiologic Fundamentals of Sinus Floor Augmentation

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Sound knowledge of maxillary sinus anatomy, physiology, biology, and possible sinus pathoses is crucial to a successful sinus floor elevation and subsequent treatment with implants that are to remain stable over years. This knowledge should be supplemented by experimental findings and clinical observations and experience.

This chapter, therefore, first explains the macro anatomy and physiology of the maxillary sinus and the maxillary alveolar process and then discusses findings of macromorphometric and histomorphometric examinations of alveolar bone, trabecular bone volume, and trabecular connectivity. Furthermore, it focuses on a description of local macroangiologic and microangiologic conditions, ie, the blood supply to the severely atrophic maxillary posterior region, and on characteristics of soft tissue covering the edentulous maxillary alveolar ridge. Results of experiments investigating the behavior of the maxillary sinus in animals toward different grafting materials are discussed, and clinical consequences of these examinations and findings are presented.

Relevant Anatomy and Physiology of the Maxillary Sinus

The antral floor is formed by the maxillary alveolar process and partly by the hard palate. In completely dentate maxillae, the antral floor constitutes the strongest bony wall of the maxillary sinus but exhibits recesses and depressions (alveolar recesses) in the pre

molar and molar regions. The cancellous bone between and above the alveoli can dehiscence with age, so that the root tips project into the maxillary sinus and are covered only by the schneiderian membrane, except for a very thin, sometimes absent, bone lamella. The deepest point of the maxillary sinus is normally located in the area of the molar roots; the next deepest area is at the premolar roots. Therefore, the risk of exposing the maxillary sinus intraoperatively is greatest when molar teeth are extracted.!

Because the mucous membrane lining the maxillary sinus, also referred to as the *schneiderian membrane*, is in direct contact with breathing air, it constitutes a kind of immunologic barrier, although to a markedly lower degree than the nasal mucous membrane. Because of this "frontline" position, frequent mild inflammation and reactive swelling associated with respiratory tract infections are not regarded as something uncommon. The schneiderian membrane is formed by a multilayered cylindrical epithelium that consists of a surface layer of ciliated and unciliated cylindrical cells, basal cells, muciparous beaker (goblet) cells, an underlying basal membrane, and the tunica propria.² It is between 0.13 and 0.5 mm thick.³

Beaker cells produce the phlegm that keeps the membrane moist, protects the ciliated epithelium, and maintains the mucociliary activity. In the schneiderian membrane, seromucous and tubuloalveolar glands are found especially near the ostium. The mainly serous secretion consists of water; small amounts of nonspecific lipids; proteins; and carbohydrates. The mucous portion of the secretion contains either compound glycoproteins or mucopolysaccharides or both.

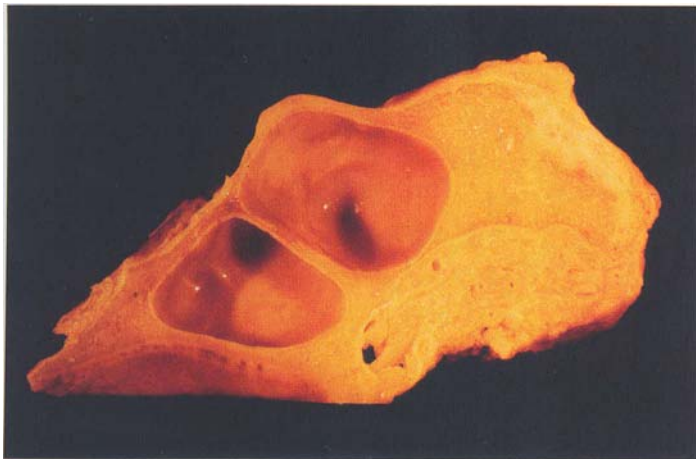


Fig 4-1 Horizontal section through the maxillary sinus of an anatomic specimen. A septum subdivides the sinus floor into two recesses.

The ciliated epithelium transports the secretion produced in the maxillary sinus to the maxillary opening at a frequency of approximately 1,000 beats per minute, from which it is drained into the nasal cavity. Cilia consist of nine and one pair of microtubules and beat regularly one after another ("metachronism"). However, their transport capacity is limited to secretions and extremely small foreign-body particles, such as dust and other particles contained in respiratory air. Cilia cannot remove larger particles, such as root residues dislocated into the maxillary sinus.

Although minor injuries of the schneiderian membrane do not impede ciliary movement and the removal of secretions, larger membrane defects or inflammation of the membrane can result in a congestion of secretions. The inflammation-free, asymptomatic maxillary sinus is completely aseptic in about 80% of the population; the remaining 20% show only a few bacteria.⁴

The volume of the maxillary sinus of adults ranges between 4.5 and 35.2 cm³; the mean volume is about 15.0 cm³.^{5,6} This means that the maxillary sinus can vary extremely in size, sinus pneumatization increasing continuously with advancing age and after tooth loss. Anteriorly, the sinus normally extends as far as the area posterior to the roots of the first premolar and sometimes even to the alveolus of the canine tooth/s. Posteriorly, the maxillary tuberosity is sometimes completely filled by an alveolar recess (especially in advanced age).

After loss of the maxillary teeth and reduction of the masticatory forces acting on the maxilla, the sinus walls get gradually thinner as a result of the increase in size of the maxillary sinus; however, they are not at risk of being fractured.⁹ With advancing age and after tooth loss, the alveolar recesses of the maxillary sinus gradually extend into maxillary regions, including the edentulous alveolar ridge, which have lost their function as

a result of progressive sinus pneumatization. This leads to an excavation of the alveolar process from the cranial aspect that varies from one individual to another. Instead of tooth roots initially anchored in this area, the alveolar ridge eventually houses variably deep sinus recesses that are situated at a markedly lower level than the floor of the main nasal cavity⁵ and can extend as far as the alveolar margin. These recesses can be roughly subdivided into an anterior depression (corresponding to the original site of the premolar buds), a middle depression (corresponding to the original site of the molar buds), and a posterior depression (corresponding to the original site of the buds of the third molar).¹⁰

In extreme cases, only a paper-thin lamella of bone separates the maxillary sinus from the oral cavity after long-term edentulism.¹¹ There is no doubt that the duration of edentulism is decisive for the extent of alveolar ridge resorption and antral pneumatization of the alveolar process.¹² Increased antral pneumatization starting after tooth loss seems to result especially from basal bone loss caused by the reinforcement of osteoclastic activity of the schneiderian membrane.^{13,14}

Asymmetries of the maxillary sinuses are common in edentulous patients, as are variably high bony septa in the area of the sinus floor (also known as Underwood's septa) (Fig 4-1). In severe cases, these septa can subdivide the maxillary sinus into two or more compartments, each with its own opening,¹⁵⁻¹⁷ and can cause complications during sinus grafting.

Examinations of edentulous cadaveric specimens revealed the following incidence and location of bone septa:¹⁷ Sinus floors with at least one septum were observed in 13 of 41 examined maxillae (31.7%). Eleven maxillae (26.8%) showed one septum each, and two maxillae (4.9%) exhibited two septa each. Underwood's septa were located in the following regions: Eleven septa (73.3 %) were found in the anterior portion of the alveolar recess, corresponding to the premolar region; three septa (19.9 %) were found in the middle portion, corresponding to the region of the first molar; and one septum (6.6%) was found in the posterior portion of the sinus floor, corresponding to the region of the second molar. In the two sinuses exhibiting two septa each, the septa were located in the anterior and middle portions of the sinus floor in one sinus and in the anterior and posterior portions of the sinus floor in the other.

The mean height of the septa was 7.9 mm, and the highest septum was 17.0 mm high.¹⁷ All septa showed frontal or largely frontal orientation; ie, they were oriented in a buccopalatal plane. No sagittal septa or septa following the arch of the alveolar process were observed. Furthermore, all septa were higher and markedly wider at their insertion sites, ie, at the buccal or palatal walls of the sinus, than in their middle por-

tions. Their typical shape thus resembled a Gothic arch standing on its head. None of the septa exhibited adequate anteroposterior width at the base for complete accommodation of an endosseous implant.

Of 15 septa, 11 were located in the premolar region, most of them at the insertion site of the zygomaticoalveolar arch, ie, at the transition to the first molar region.¹⁷ Because premolar teeth are retained longer than are molar teeth, on statistical average, the formation of septa might be promoted by the different phases of sinus pneumatization. This assumption is also supported by the fact that the sinus floor frequently was found to be on different levels anterior and posterior to a septum. It seems that the floor of the alveolar recess in the edentulous molar region already reaches a deeper level at an earlier stage. In the premolar region, on the other hand, pneumatization takes place after the premolars have been lost, which generally occurs much later. For biomechanical reasons, a bony septum is left in the region between these two zones of regression to allow a transfer of masticatory pressure.

Underwood¹⁵ also described septa whose edge margins showed canals for the transmission of vessels and nerves from one side of the cavity to the other.

Resorption of the Edentulous Maxillary Alveolar Ridge

After tooth loss, the maxillary alveolar process undergoes progressive, irreversible resorption that results in a massive loss of substance, both vertically and horizontally. Atrophy-related bone resorption markedly reduces the local host bone available for implant placement over the years.¹⁸

The extent of bone resorption in the maxillary posterior region depends on the duration of edentulism in this area and on the residual dentition anterior to the maxillary sinus, which slows down resorption in the area of terminal gaps.⁹ Only rarely is sufficient host bone available between the maxillary sinus and the alveolar ridge after long-term edentulism and progressive resorption of the maxillary alveolar process, particularly because the alveolar recesses tend to expand less into the alveolar ridge in these cases. However, in most cases, the available host bone does not suffice for anchorage of endosseous implants, especially in the molar region.¹⁹

There are many causes of alveolar ridge resorption. The frequency, direction, and intensity of forces acting on the alveolar process play an important role as the construction and fit of the prosthetic restoration used. Furthermore, resorption can be accelerated and the bone density reduced by systemic factors, such as the

patient's age and sex, as well as by hormonal imbalances, metabolic factors, and inflammation.¹⁵

The most severe resorption occurs immediately after tooth loss, as a result of resorptive and remodeling processes affecting the empty alveoli because of an absence of functional loading. Vertical bone loss at the maxillary alveolar process then proceeds at a rate of approximately 0.1 mm per year and can vary greatly from one individual to another.^{20,21}

Classification of residual alveolar ridges

Following long-term studies of the mandible, Atwood^{21,22} was the first to point out that resorption of the edentulous alveolar ridge follows a characteristic pattern. In continuation of these studies, Fallschiesse³ established his own classification for the maxillary alveolar process that was later slightly modified by Cawood and Howell^{4,25}. The latter also pointed out that there are morphologic differences in the atrophic patterns between the anterior and the posterior regions, and developed a more subtle classification for the posterior region. Cawood and Howell's classification of edentulous jaws²⁴ comprises the following residual ridge classes (Fig 4-2):

- Class 1: Dentate
- Class 2: Immediately postextraction; the alveolus has healed
- Class 3: Well-rounded ridge, adequate in height and width
- Class 4: Knife-edged ridge, adequate in height and in adequate in width
- Class 5: Flat ridge, inadequate in height and width
- Class 6: Depressed ridge with varying degrees of basal bone loss that may be extensive but follows no predictable pattern

Because there is a clear correlation between the resorptive class of the edentulous alveolar ridge and the vertical and horizontal bone volume available for implant placement, this classification has proved worthwhile for presurgical diagnostic evaluation. However, no reliable data are available on the relative incidence of the different resorptive classes.

Quantification of bone resorption

In a study carried out at the Department of Oral Surgery of the Dental School of the University of Vienna, 47 anatomic specimens were sectioned vertically and classified according to Cawood and Howell's classification of edentulous jaws²⁴ to quantify the bone loss in the molar region of the maxillary alveolar process.

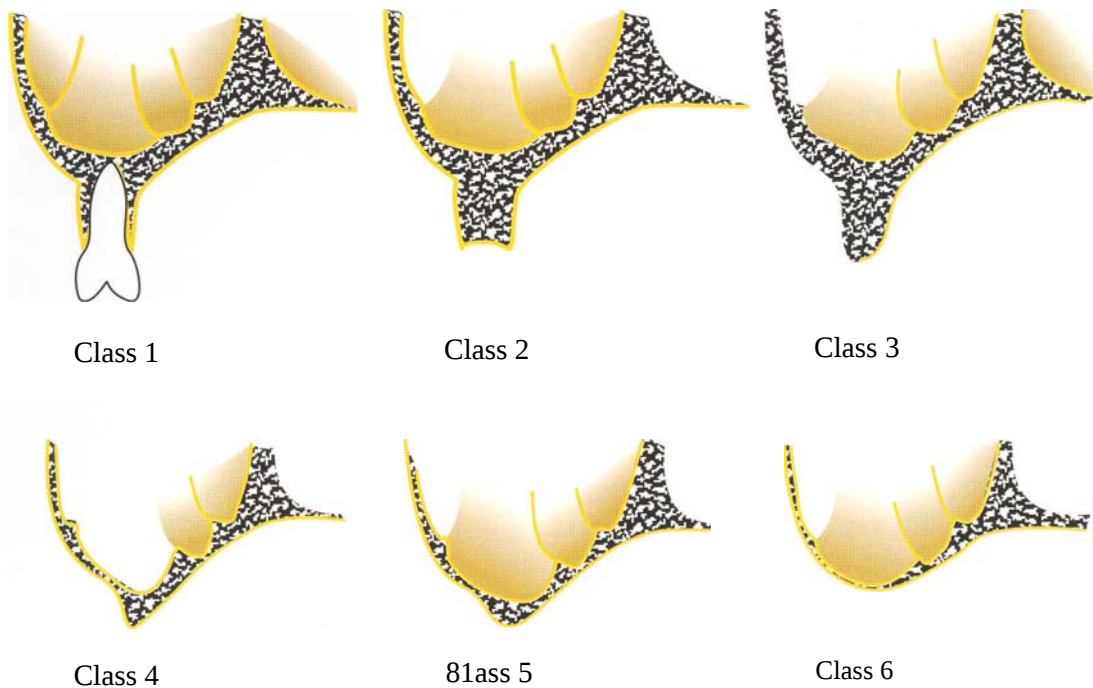


Fig 4-2 Cawood and Howell's classification of edentulous jaws.²³

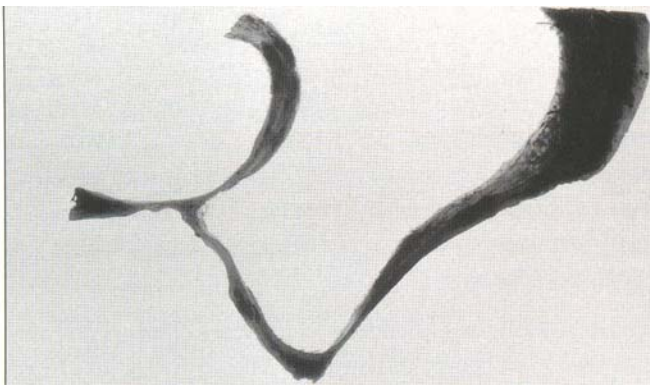


Fig 4-3 Cross section through the maxillary alveolar process in the region of the first molar. Only a thin lamella of compact bone separates the maxillary sinus from the oral cavity. The maxillary sinus has excavated the still rather high and wide alveolar ridge from retrograde (left = palatal; right = buccal).

Computer-assisted measurements of alveolar ridge height and width were carried out to assess the bone volume available for endosseous implant placement. The following results were obtained.

Height of the alveolar ridge (distance between the crest of the alveolar ridge and the floor of the maxillary sinus)

The mean ridge height varied between 9.30 and 3.23 mm. The highest and the lowest values obtained were

13.80 mm and 0.80 mm, respectively. The latter value illustrates how long-term edentulism may result in bone remodeling and resorption and progressive sinus pneumatization, leaving only a thin cortical plate to separate the antrum from the oral cavity²⁵ (Fig 4-3).

Width of the alveolar ridge (measured at 1.00 and 3.00 mm below the ridge crest)

The mean values obtained at 1.00 mm below the ridge crest showed that the majority of ridges offer sufficient

width to accommodate endosseous implants.²⁶ Only in classes 4 and 6 of Cawood and Howell's classification²⁴ did some values, ranging between 1.80 and 3.00 mm, clearly indicate that small, knife-edge ridges can be present in the maxillary posterior region. However, they are more common in the maxillary anterior region or in the mandible. Measurements of the alveolar ridge width at 3.00 mm below the ridge crest revealed that the alveolar ridge gets markedly wider in a cranial direction, showing mean values between 5.02 and 8.75 mm.

The findings of this study clearly indicate that the limiting factor for endosseous implant placement in the maxillary posterior region is not the width but the height of the alveolar ridge, ie, the available vertical bone volume. The bone loss in this region results not only from alveolar ridge resorption but also from increasing maxillary sinus pneumatization. Sinus pneumatization even seems to have a much greater influence on bone loss, because some alveolar ridges that appeared to offer an adequate height and width from the outside exhibited only a millimeter-thin bone lamella between the sinus floor and the floor of the oral cavity.¹¹

Bone Quality of the Edentulous Maxillary Alveolar Ridge

Compared to dentate maxillae, edentulous maxillary regions show a clearly looser cancellous bone structure that seems to be denser in the anterior region than in the premolar-molar region. Lekholm and Zarb²⁷ distinguished four morphologic types of edentulous jaws, taking into account both cortical and cancellous bone: type 1-homogenous cortical bone, no cancellous bone; type 2-thick cortical compartment, variably sized cancellous portion; type 3-thin cortical compartment, dense cancellous portion; type 4-extremely thin compact layer, cancellous bone of reduced density. Although types 1 and 2 are typical of the mandible, types 3 and 4 are found mainly in the maxillary alveolar process. Jaffin and Berman²⁸ reported a great number of losses of Branemark implants (Nobel Biocare) in type 4 bone and showed that alveolar cancellous bone of reduced density is correlated with a loss of endosseous implants. This implies that the density and architecture of the trabecular host bone are crucial to the stability of endosseous implants in the alveolar ridge.

The structural qualities of cancellous bone can be precisely assessed only with the help of histomorphometric measurements because none of the radiographic, microradiographic, or computerized tomographic methods is precise enough for structural analyses. Therefore, a study carried out at the Department of Oral Surgery of the Dental School, University of Vi

enna, analyzed edentulous maxillae of 52 cadavers (29 female and 23 male; mean age = 72.5 years) and a total of 134 5-mm-thick bone sections obtained from the maxillary alveolar process in the regions of the lateral incisor, the first premolar, and the first molar. The undecalcified bone sections were embedded in plastic resin and a 20- μ m-thick ground section was then prepared for each region using the sawing and grinding technique.²⁹ The surfaces of the sections were impregnated with von Kossa's silver stain, and their images were then scanned into an automatic image-analyzing system.

The trabecular bone volume (in %) and trabecular bone pattern factor (BPF) (in mm-l) were calculated^{30,33}:

$$\text{Trabecular bone volume} = \frac{\text{Bone area}}{\text{Analyzed area}}$$

$$\text{Trabecular bone pattern factor} = \frac{\text{Bone perimeter} - \text{Dilated bone perimeter}}{\text{Bone area} - \text{Dilated bone area}}$$

The trabecular bone pattern factor is based on the idea that the connectivity of cancellous bone structures in a two-dimensional section can be described by the relation of convex to concave structures. Concave structures represent well-connected cancellous bone, and convex surfaces indicate the contrary. Bone area and bone perimeter are measured before and after arithmetic dilatation of the binary image of the bone compartment. Dilatation results in a characteristic change in these parameters, depending on the relation of convex to concave surfaces. Well-connected trabeculae show mainly concave borders to the surrounding areas, whereas badly connected structures are convex because of free-ending trabeculae (Fig 4-4). The higher the degree of trabecular connectivity, the lower the TBPf, and the lower the degree of trabecular connectivity, the higher the TBPf (Fig 4-5).

Generally, the trabecular bone volume can vary extremely among edentulous maxillae. A difference of more than 45% between the highest trabecular bone volume (51.93%, measured in the incisal region) and the lowest trabecular bone volume (6.73 %, measured in the molar region) illustrates the possible range of variation. Statistical results of the structural histomorphometric measurements carried out in the anterior, premolar, and molar regions are given in Table 4-1.

The TBPf values indicate that trabecular bone of female maxillae is less connected than that of male maxillae (Fig 4-5). The correlation between trabecular bone volume and TBPf is due to the fact that a high trabecular bone volume inevitably results in a higher degree of connectivity. However, TBPf is a more sensitive parameter because even minimal changes in the trabecular microarchitecture, caused, for example, by osteoclastic trabecular perforations, result in much faster changes in TBPf than in trabecular bone volume.³²

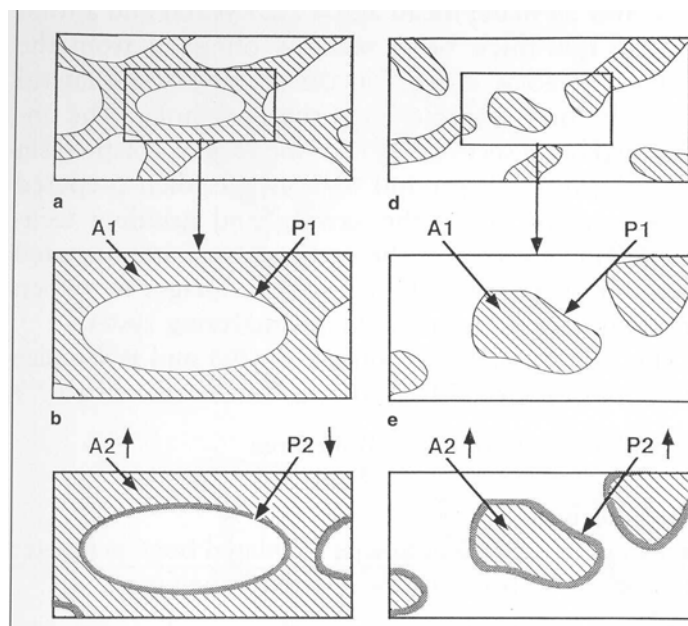


Fig 4-4 Trabecular bone pattern factor (TBPf) principle. Measurements of bone area (A 1) and bone perimeter (P1) are carried out (b and e). The trabeculae are then dilated (by adding 1 pixel to each trabecular surface) and become thicker (c and f). The thus enlarged bone area (A2) and the bone perimeter (P2), which either increases or decreases depending on whether convex or concave structures predominate, are measured. If cancellous bone shows a high degree of connectivity (a, b, and c), concave trabecular perimeters predominate and TBPf is low. If there is a low degree of connectivity, as, for example, in bone affected by osteoporosis-convex trabecular perimeters predominate and TBPf is high (d, e, and f).

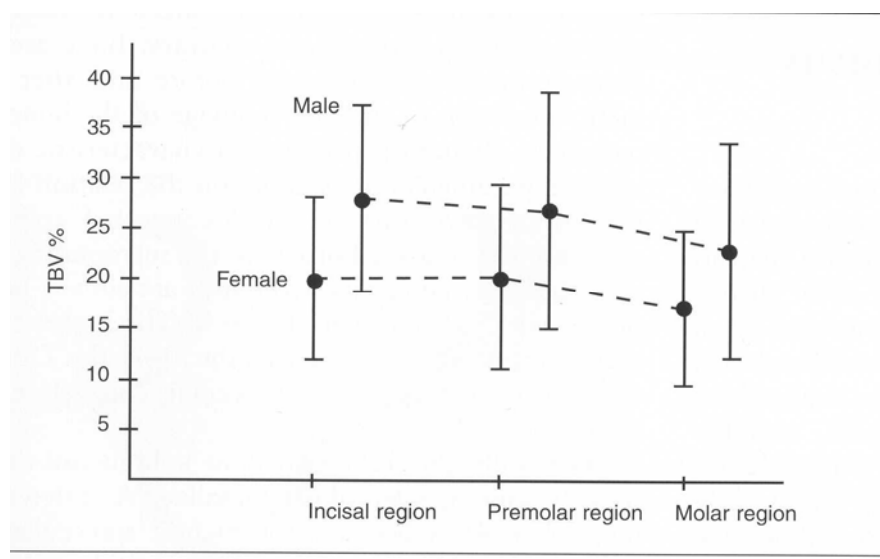


Fig 4-5 Mean (SD) trabecular bone volume (TBV) in the maxillary incisal, premolar, and molar regions.

Table 4-1 Measurement results for trabecular bone volume and trabecular bone pattern factor of 134 undecalcified bone sections

Region	Sex	n	Trabecular bone volume (%)		Trabecular bone pattern factor (mm-l)	
			Mean	SO	Mean	SO
12	Female	29	20.2	7.76	+0.171	1.79
12	Male	23	27.9	8.64	-1.106	1.75
P 1	Female	29	20.5	8.50	+0.450	1.60
P 1	Male	18	26.7	11.36	-0.562	1.82
MI	Female	22	17.1	7.30	+0.123	1.68
MI	Male	13	23.4	9.49	-0.708	1.72

I 2 = region of the lateral incisor; P 1 = region of the first premolar; M 1 = region of the first molar.

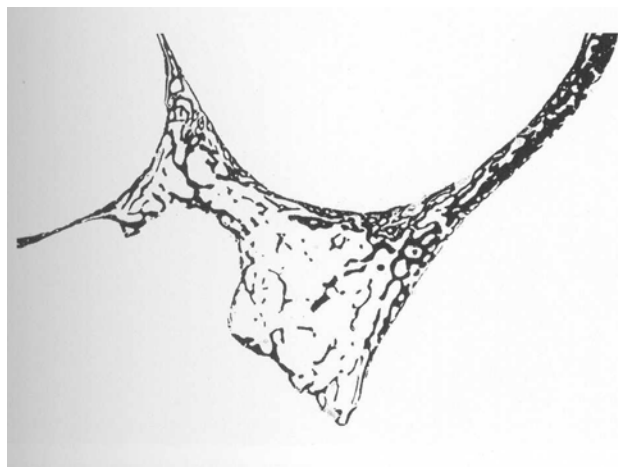


Fig 4.6 Cross section through the alveolar process in the region of the first molar (left = palatal; right = buccal). The trabecular bone is distributed inhomogeneously. Trabecular thickness and number vary significantly and are markedly reduced crestally and palatally, as compared to buccally, where the trabecular bone is rather dense and well connected. The entire alveolar process is surrounded by extremely thin cortical bone that has become perforated in several sites. (von Kossa's staining.)

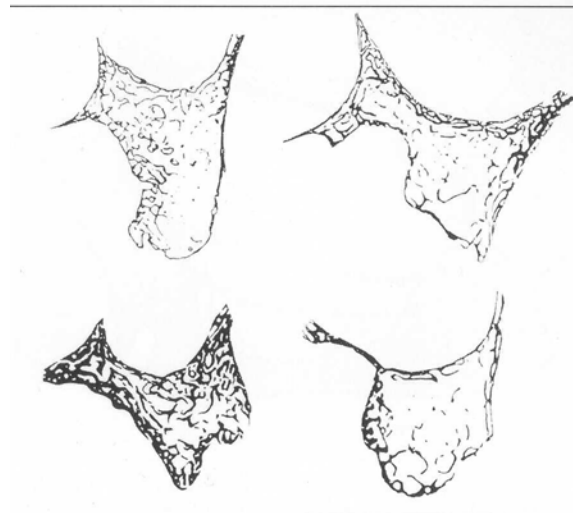


Fig 4.7 Four frontal sections in the region of the first and the second molars (left = palatal; right = buccal). There is a great difference in the density (TBV) and the structure and connectivity (TBPf) of cancellous bone among these sections. Because many trabeculae exhibit free endings, connectivity and biomechanical stability are considerably reduced. Some alveolar ridge areas even lack trabeculae, whereas others show a clearly denser structure. An extremely thin layer of compact bone has become perforated in some sites. The bone volume is extremely small. (von Kossa's staining.)

As can be clearly seen in Table 4-1, the morphology of cancellous bone varies significantly from one region to another. The molar region, for example, showed slightly less cancellous bone with a lower degree of connectivity than did the anterior and premolar regions. Cortical bone seemed to be reduced as well (Figs 4-6 and 4-7). A possible explanation for this might be that the molars are lost rather early in most cases.³⁴ The duration of edentulism, local mechanical and inflammatory factors, and the type of prosthetic restoration used are possible causes of the inferior cancellous bone quality in this region. It is also possible that the cancellous substance in this region has a loose structure, irrespective of age and dentition.

The morphologic evaluation also revealed that thin crestal cortical bone with openings into marrow space predominated in this region (Figs 4-6 and 4-7). According to both Nakamoto³⁵ and Pietrokovski⁶ these openings are caused by continuous resorption of the crest, resulting in exposure of areas of cancellous bone to the alveolar ridge.

Noticeable variations in trabecular microarchitecture and bone volume within individual sections of the same region were observed, especially in the molar region, and ranged from a sometimes rather dense to an extremely loose cancellous bone structure. Palatal trabeculae frequently showed a denser configuration than buccal and crestal trabeculae. This difference might re-

sult from incompletely repaired alveoli after tooth loss, mild local inflammation, or local remodeling processes caused by the different loading patterns of prosthetic restorations^{35,37} (Figs 4-6 and 4-7).

Sex-specific differences were found in all examined regions (see Table 4-1 and Fig 4-5); female maxillae showed less cancellous bone with a lower connectivity than did male maxillae. The advanced mean age of the deceased (72.5 years) suggests that these differences result from increased postmenopausal bone loss. Such an influence, and subsequent osteoporosis, has been discussed by several authors.^{9,21,3s,39}

Vascular Supply to the Maxillary Sinus and the Edentulous Maxillary Alveolar Ridge

Arteries supplying the maxillary sinus are branches of the maxillary artery (the posterior superior dental artery; the anterior superior dental arteries coming from the infraorbital artery; the greater palatine artery and the lesser palatine arteries coming from the descending palatine artery; and the lateral and posterior nasal branches of the sphenopalatine artery) and the facial artery. The venous flow occurs via the facial vein, the sphenopalatine vein, and the pterygoid plexus.⁴⁰

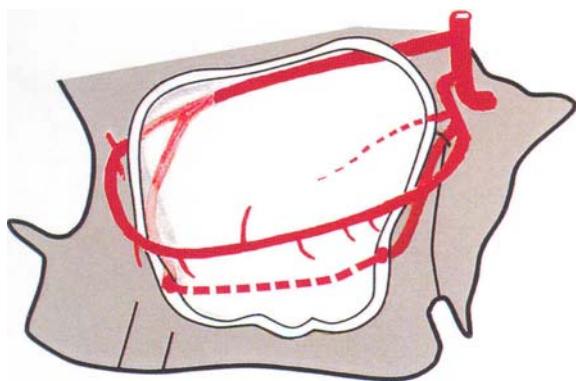


Fig 4-8 Vessels supplying the buccal antral wall (left = ventral; right = dorsal). The infraorbital artery and the posterior superior dental artery form an intraosseous anastomose (*broken line*) in all cases and an extraosseous anastomose (*continuous line*) in 40% of the cases.



Fig 4-9 Fluoroscopy of the buccal antral wall of an anatomic specimen (left = dorsal; right = ventral). The arterial anastomose between the posterior superior dental artery and a branch of the infraorbital artery, which forms an arch caudally, below the zygomaticoalveolar process, is clearly discernible.

As far as soft tissue covering the atrophic alveolar ridge is concerned, it is assumed that the border between the arterial vessels is located in the area where the buccal mucous membrane (supplied by branches of the posterior superior dental artery and the infraorbital artery) and the palatal mucous membrane (supplied by branches of the greater palatine artery) grow together.

The maxilla is supplied with a comparatively dense vascular network. Microangiographic studies in monkeys have revealed a very dense micro anastomose of maxillary vessels.⁴¹ Loss of maxillary teeth and advancing age result in a marked reduction in bone vascularization. The decrease in vessels is accompanied by a reduction of the lumen and an increase in tortuosity.⁴²⁻⁴⁴ In human bones, there is a connection among the development of microvascular defects, bone atrophy, and age.⁴⁵ Stenotic changes reduce the intramedullary blood flow to such an extent that osteoblastic activity is inhibited and the process of bone mineralization is delayed.⁴⁶ This means that atrophy of the maxillary alveolar process is associated with a decrease in vessels.

The vascular supply to the lateral antral wall and the antral floor is of special interest to maxillofacial and implant surgery. Solar et al⁴⁷ analyzed the vascular supply to the maxillary sinus and the alveolar process in an anatomic study carried out in 18 edentulous skull specimens. The results of this study indicate that the buccal antral portions are supplied by two arteries: the posterior superior dental artery and the infraorbital artery. An intraosseous arterial anastomose was found between these two arteries in all cases (Figs 4-8 and 4-9). The endosseous portions of these anastomoses gave off a variably sized network of very fine branches, in the sense of a plexus, especially caudally, toward the maxil

lary alveolar process. Furthermore, an extraosseous vestibular vascular anastomose was observed in 44% of the cases.

The posterior superior dental artery and the infraorbital artery also supply the mucous membrane of the lateral maxillary sinus and the local oral mucosa in the form of a double circulus arteriosus. The medial portion of the antral mucosa is supplied by the sphenopalatine artery.⁴⁸ The maxillary sinus shows a sparser vascular network than the nasal cavity. Although the fine vessels in the antral mucosa are dichotomous in most cases, there are also numerous recurrent branches. The capillary network has meshes that differ considerably in size, getting larger further away from the vascular trunk (Figs 4-8 and 4-9).

Soft Tissue Covering the Edentulous Maxillary Alveolar Ridge

The soft tissue covering the edentulous maxillary alveolar ridge differs fundamentally between the palatal and the buccal regions. Palatally, the soft tissue is markedly tighter and becomes gradually thicker from anterior to posterior. It is characterized by a great percentage of submucous glandular and fatty tissue. Solar et al⁴⁷ carried out a computer-assisted histomorphometric analysis of the palatine mucosa in histologic ground sections of 18 anatomic specimens. Their findings indicate that the palatine soft tissue gets thicker from anterior to posterior (mean thickness in the anterior region, 4.4 mm; mean thickness in the molar region, 7.1 mm), while the lamina propria gets thinner. Therefore, the

zone formed by fat and glands gets closer and closer to the mucosal surface further posteriorly.

Buccally, the soft tissue covering the maxillary alveolar ridge is markedly thinner (between 1.5 and 3.5 mm⁴⁷) and less firmly attached to the alveolar bone. Because of the difference in soft tissue thickness between the buccal and palatal regions and the high percentage of fatty and glandular tissue palatally, it is often necessary to thin the palatal portion of the peri-implant soft tissue cuff at the site where the implant passes through the mucosa and to adapt it to the buccal soft tissue conditions for hygienic and esthetic reasons (Fig 4-10).

Response of the Maxillary Sinus to Grafting Materials

Classification of biocompatibility

In principle, not only exogenous substances are foreign bodies to the organism, but also endogenous tissue that has lost its functional connection with local tissue.⁴⁹ Host tissue has a specific effect on these foreign materials that varies, depending on the site in which the foreign material is placed.⁵⁰

The same material can trigger different reactions, depending on whether it is placed in soft or hard tissue. For example, in soft tissue, amalgam results in multinuclear giant cells and collagenous fibrils with phagocytosis of small amalgam particles, whereas an intimate contact with bone can be observed over extensive stretches when amalgam particles are located in bone marrow.

The response of tissue, especially bone tissue, to foreign materials is often considered an indicator of the biocompatibility of these materials. Heimke⁵¹ subdivided grafting materials into three groups, depending on their biocompatibility: biotolerated materials, bioinert materials, and bioactive materials. *Biotolerated materials* cause irritation of the surrounding host tissue with subsequent differentiation of precursor cells into osteoblasts and formation of a collagen-rich intermediate layer (distant osteogenesis). *Bioinert materials* have no effect on the surrounding tissue in the sense of a cellular response. The result is no enzyme reaction and the implant is "camouflaged" against the host's immune system. No foreign-body reaction occurs, and a contact osteogenesis is possible. *Bioactive materials* result in an apposition of collagen and hydroxyapatite to the implant surface, starting from the surrounding bone (bonding osteogenesis).

However, this classification does not take into account the biologic effect of the grafted substance itself, as does the classification established by Thielemann et al.⁵²

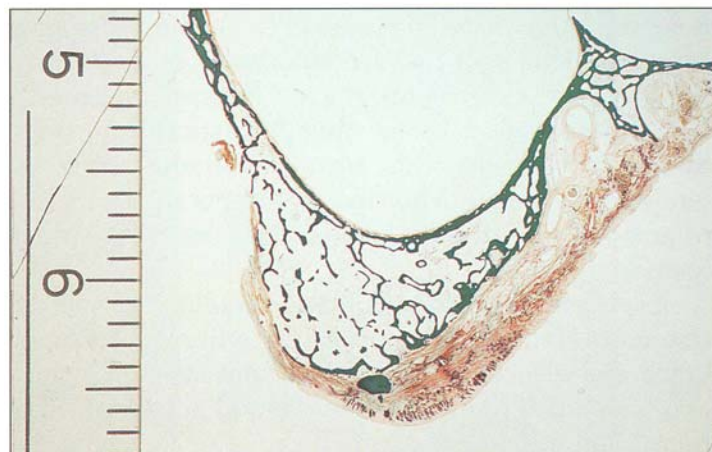


Fig 4-10 Undecalcified ground section from the region of the second molar (left = buccal; right = palatal). The trabecular alveolar bone (green) shows a looser, yet well-connected, structure. The mucous membrane covering the edentulous alveolar ridge (reddish brown) is formed by residual attached gingiva buccally and by a thick palatine mucosa interspersed with connective, fatty, and glandular tissue palatally, which have grown together in the area of the alveolar margin after tooth loss. (Masson-trichrome Goldner staining.)

According to these authors, osteoconductive grafts (eg, collagen preparations, macerated bone, porous ceramics, and cancellous bone) serve as a guide rail for new bone formation starting from bone, whereas osteoinductive grafts (eg, demineralized bone matrix and its higher purified factors) induce morphogenesis, cytodifferentiation, and organogenesis in the sense of new bone formation, also heterotopic ally, within the organism.

Factors in the success of a sinus graft

Irrespective of the above-mentioned factors, the success of a grafting procedure using bone or bone substitute materials depends basically on the following host site factors:

1. The proliferative capacity of the host site (host site with either a low or a high or no capacity for new bone formation)
2. The vitality of the host site and its capacity to revascularize the grafting material
3. The volume and size of the defect to be restored by bone tissue ingrowth
4. The stability of the grafting material within the host site
5. The concentration of bone morphogenetic protein on the surface of the host bone
6. The metabolic activity index of the respective organism

The maxillary sinus must be considered a border line case regarding all these points, because bone or

bone substitute material placed in the subantral space is surrounded not only by bone but also by connective tissue portions of the antral mucosa (mucoperiosteum).⁴⁰ It is also possible that new bone formation is impaired by micromovements of the antral membrane during respiratory movement. Movement prevents the formation of new bone and results in connective tissue sheathing (pseudoarthrosis).

Especially in severely atrophic maxillae, the surgical trauma caused by elevation of the schneiderian membrane and formation of a lateral bone window, which may jeopardize the endosseous blood supply to local bone,⁴⁷ must not be underrated.

Evaluation of the biologic response to sinus grafting

Case studies

Histologic studies investigating the use of different grafting materials in sinus elevation surgery have discussed either autopsy specimens in single-case studies⁵³⁻⁵⁶ or biopsy specimens obtained during implant placement in two-stage sinus elevation procedures.^{57,58} Histomorphometric analyses of such tissue samples have investigated the bone volume in relation to the augmented area and connective tissue. Moy et al⁸ reported on five patients after an observation period of 6 to 25 weeks and found 20.3 % bone per area examined when nonresorbable hydroxyapatite was used, 4.6% when hydroxyapatite was combined with demineralized bone powder, 59.4% when grafting was done with intramembraneous bone alone, and 44.4% when intramembraneous bone was placed in combination with hydroxyapatite.

Hanisch et al⁹ also reported on five patients, observing 20.7% of newly formed bone on average in biopsies taken 12 months after internal augmentation with a mixture of demineralized, freeze-dried cortical bone and bovine hydroxyapatite. However, such studies have only limited indicative value, at best providing an orientation about probable anchorage of dental implants after placement.

Experimental studies

Experimental studies in sheep therefore aimed to examine the validity of the sinus graft procedure histologically and histomorphometrically.^{6D} For this purpose, the schneiderian membrane was elevated via an extraoral, lateral access and the submucous hollow space was filled with either bovine hydroxyapatite (Bio-Oss, Geistlich) or 4 to 6 cm³ of cancellous bone from the ipsilateral iliac crest. Two 8-mm-long cylindrical implants

with titanium plasma-sprayed surfaces were placed in the same session. Maxillary sinuses into which implants were placed without prior augmentation were used as the control group. To ensure that the results were comparable, the implants were neither exposed to the oral environment nor treated prosthetically.

The observation periods used were 12, 16, and 26 weeks. One implant per maxillary sinus was then prepared histologically.

Formation of new bone. Light microscopically, all implants in the control group showed new bone formation in a triangular area formed by the implant surface, the local bony antral wall, and the submucous connective tissue. None of the specimens showed new bone formation originating from the tissue adjacent to the schneiderian membrane (Fig 4-11).

All different stages of new bone formation were discernible. Areas with osteoblastic seams, granular preosteoid deposits, and osteoid formation were found, as were osteoclasts. The hard tissue showed a woven structure after 12 weeks and a largely lamellar structure with regular osteons after 26 weeks. Mononuclear and multinuclear macrophages surrounded by a network of collagenous fibers oriented parallel to the implant surface were observed on bone-free surfaces.

In sinuses augmented with autogenous cancellous bone from the iliac crest and bone marrow, too, the peri-implant hard tissue covered mainly crestal implant portions, while apical implant portions were surrounded mainly by loose connective tissue. Cancellous bone formations with bone-marrow-like hollow spaces around the implant apex were observed only in some specimens (Figs 4-12a and 4-12b).

A striking finding was that the originally placed cancellous bone grafts had undergone considerable resorption. Only one specimen showed circumscribed hyaline cartilage formation after 26 weeks. Lamellar remodeling was concluded after 26 weeks in most specimens.

In sinuses augmented with bovine hydroxyapatite, a bioactive and osteoconductive⁶¹ inorganic bone matrix, the crestal implant portions were in intimate contact with bone tissue. When apatite granules were adjacent to local maxillary bone, they were partly surrounded by bone tissue in a wallpaper-like fashion, partly walled in by solid, unstructured bone areas. No new bone was formed around the foreign material further away from these areas. There was a great discrepancy regarding the extent of bony sheathing of hydroxyapatite granules, irrespective of the animal's survival time. While some specimens showed only minimal new bone formation, others exhibited compact hard tissue also above the implant apex. Collagenous fibers and macrophages were appositioned to bone-free surfaces of the hydroxyapatite granules. Circumscribed, less in

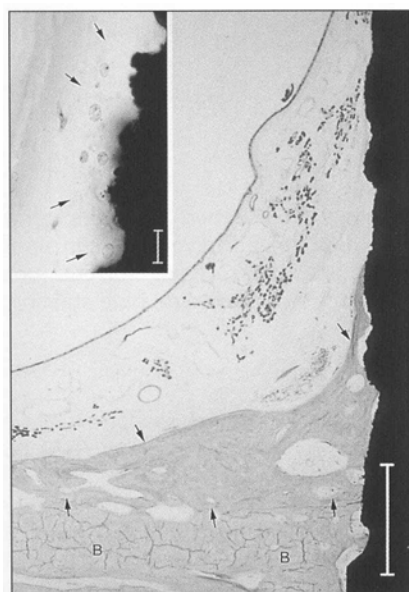


Fig 4-11 Longitudinal section through an implant 16 weeks after placement in the elevated subantral space without any further augmentation. (B) Local bone; (arrows) newly formed bone. (Toluidine blue staining; bar = 1 mm.) Inset: Histiocytic giant cells (arrows) on the implant surface. (Toluidine blue staining; bar = 10 μ m.)

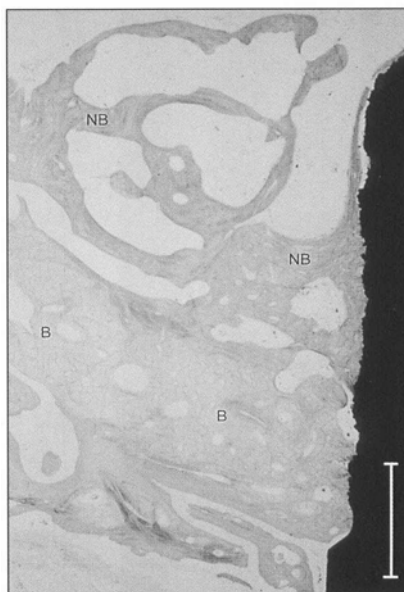


Fig 4-12a Frontal section through an implant 26 weeks following augmentation with autogenous cancellous bone from the iliac crest. (B) Local bone; (NB) newly formed bone. (Toluidine blue staining; bar = 1 mm.) Reprinted with permission from Haas et al.; @ 1998 Munksgaard International Publishers Ltd, Copenhagen, Denmark.

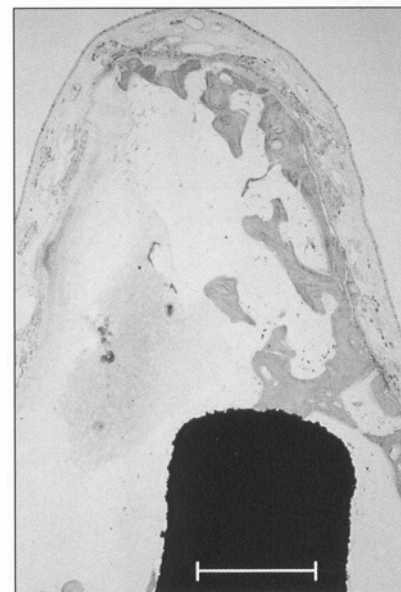


Fig 4-12b Apical portion of an implant 26 weeks after augmentation with autogenous cancellous bone showing circumscribed hyaline cartilage formation. (Toluidine blue staining; bar = 1 mm.)

tensely stained, areas and formation of resorptive lacunae were observed adjacent to these cells (Figs 4-13a and 4-13b).

The histologic appearance therefore resembled the course of chronic inflammation in marginal bone areas,⁶² whose characteristic feature is a decrease in macrophages on the foreign-body surface, with increasing bone apposition.^{62,63} This osteoconductive behavior is a property of bone tissue and can be observed in other materials placed in bone.^{50,62-64} Hard tissue sheathing of ceramics and titanium implants, starting from maxillary bone, therefore constitutes a reaction of the organism to render foreign bodies innocuous. This happens in all sites, where a certain immobility is guaranteed. The deeper within submucous mobile tissue incapable of bone regeneration the grafting material is located, the more collagenous fibers running parallel to the surface (fibrous capsule) can be observed. This regenerative tissue has no bone precursor cells or preosteoblasts; it produces collagen-rich connective tissue and ends as a fibrous scar.⁶² The histologic results of the experimental sinus elevation procedures in sheep are therefore consistent with the behavior that can be expected from foreign tissue at the border between the bony antral wall and the fibrous mucoperiosteum.

Measurement of bone-implant contact. The mean length of the bone-implant contacts resulting from this tissue response was up to 25.1 % in the control group, 35.5% in the group augmented using cancellous bone, and 34.7% in the hydroxyapatite group, irrespective of the observation period.⁶⁰ The longer the implants were left in situ, the greater the increase in the length of the direct bone-implant contact in all three groups.

Although no significant overall increase in the length of the bone-implant contact in the hydroxyapatite group could be observed in comparison to the control group, a significant increase in the length of the bone-implant contact was achieved at the implant apex. Although autogenous cancellous bone from the iliac crest resulted in a significantly greater bone-implant contact than was found in the control group or the hydroxyapatite group, the original volume of the autogenous cancellous iliac crest grafts was considerably reduced. These findings are consistent with those of Smiler et al,⁶¹ who observed no or insufficient new bone formation in patients who had undergone maxillary sinus augmentation using bone tissue alone.

A possible explanation for this might be that the graft is placed extracorporeally, without an adequate blood supply. Furthermore, after having been placed in

4 Anatomic and Physiologic Fundamentals of Sinus Floor Augmentation

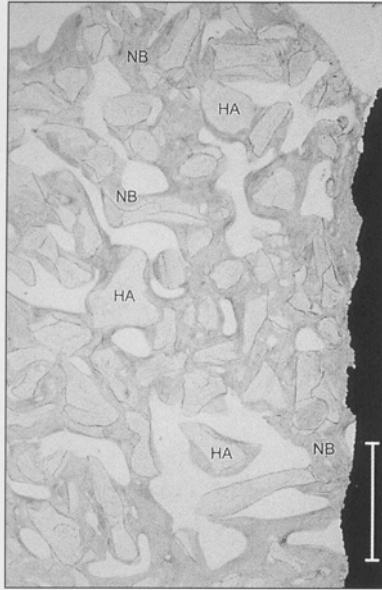


Fig 4-13a

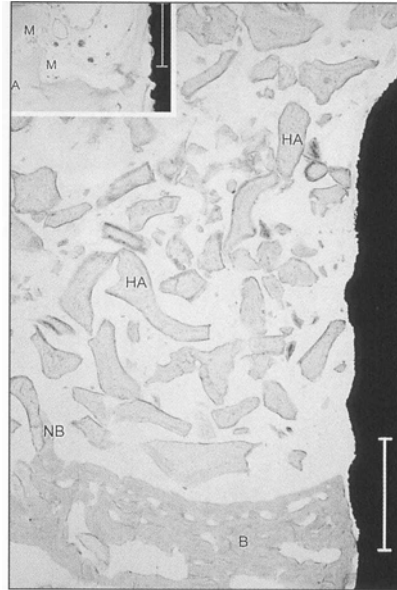


Fig 4-13b

Fig 4-13a Longitudinal section 26 weeks following augmentation with bovine hydroxyapatite and simultaneous implant placement. (NB) Newly formed bone; (HA) bovine hydroxyapatite. (Toluidine blue staining; bar = 1 mm.)

Fig 4-13b Similar longitudinal section at 26 weeks. (B) Local bone; (NB) newly formed bone; (HA) bovine hydroxyapatite. (Toluidine blue staining; bar = 1 mm.) Inset: Histiocytic giant cells (M) on the apatite surface (HA). (Toluidine blue staining; bar = 10 J.1m.) Note the considerable difference between Figs 4-13a and 4-13b in bony sheathing of the foreign material.

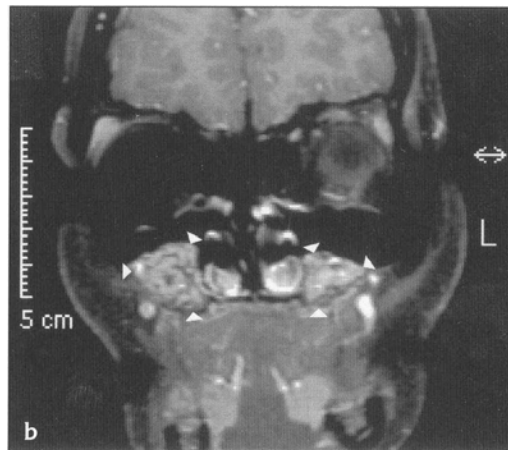
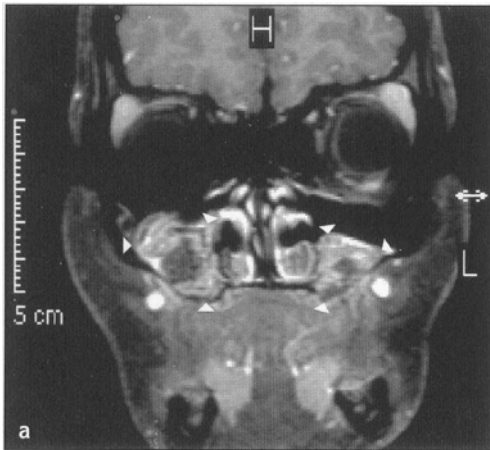


Fig 4-14 Nuclear magnetic resonance image with contrast agent of a patient 4 weeks (a) and 14 weeks (b) after receiving a sinus graft in both maxillary sinuses using autogenous bone from the iliac crest. (arrows) Receptient site. Note the difference in vascular supply of the graft: the central area (black), nonvascularized after week 4, is vascularized after week 14. (Courtesy of G. Mailath.)

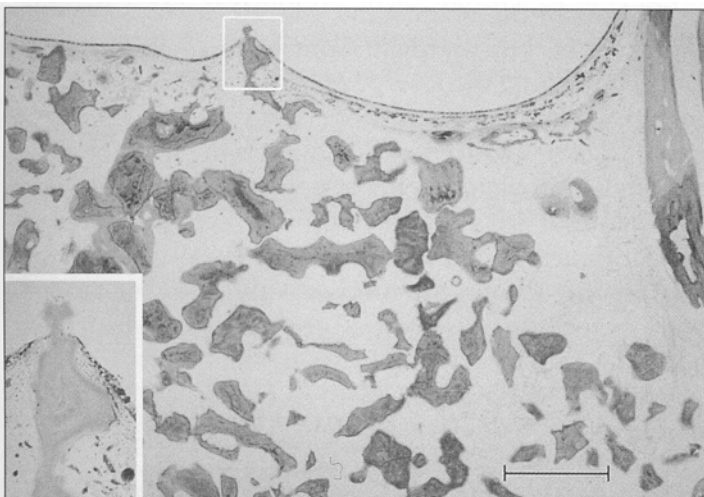


Fig 4-15 Sinus graft in sheep 16 weeks after augmentation with hydroxyapatite. Note the migration of one granula through the sinus membrane and slight chronic inflammation in the surrounding submucous tissue. (Toluidine blue staining; bar = 1 mm.) Inset: Higher magnification of the boxed area.

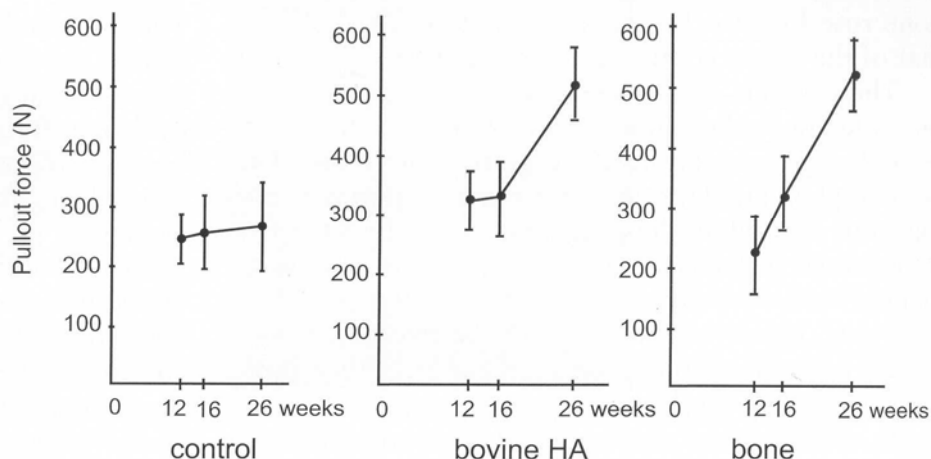


Fig 4-16 Mean pullout force (least square means $\pm$ SEM) N of the nonaugmented control group and the two groups augmented with bovine hydroxyapatite or autogenous cancellous bone.

the subantral hollow space, the graft is supplied only via diffusion and is vascularized only after days or weeks (Fig 4-14). A large percentage of the grafted osteoblasts and precursor cells die as a result of the long phase, during which the graft is without vascular supply. Bone thus denuded of lining cells, activates osteoclasts⁶⁵ that rapidly resorb it. On the one hand, this results in a reduction of the graft's biomechanical stability; on the other hand, an increasing amount of calcium is available for new bone formation.⁶⁶

Morphology of the schneiderian membrane. The schneiderian membrane showed no morphologic changes at the light microscopic level. No change in columnar ciliated epithelia and mucus-producing, secretory goblet cells was found.⁶¹ Occasionally, migration of a foreign body through the sinus membrane may occur (Fig 4-15). The same findings were obtained in endoscopic recall examinations and schneiderian membrane biopsy specimens obtained from patients whose mucoperiosteum had been damaged during implant placement.^{7,67}

Mechanical Loading Capacity of Implants Placed in Augmented Maxillary Sinuses

In experimental pullout tests in animals, forces of 277 N and 821 N were required in the maxilla and the compact mandible, respectively, to destroy the bone-implant bond formed by cylindrical plasma-sprayed implants after a period of 24 weeks.⁶⁸

Because no studies on the loading capacity of the bone-implant bond following sinus elevation surgery

are available, the second implant placed in the maxillary sinus in the aforementioned experiment in sheep was used for mechanical testing.⁶⁹ For the testing procedure, the specimens were embedded in self-curing polymethylmethacrylate (Technovit 4071, Kulzer) with an elastic modulus of 3,353 $\pm$ 235 N/mm². The implants were then subjected to strictly axial pullout forces. The measurements ranged from 0 to 1,000 N, at a pullout speed of 0.4 mm/min, until failure of the bone-implant bond.

The mean pullout strength of implants placed in augmented and nonaugmented maxillae was 265.7 N after 12 weeks, 305.2 N after 16 weeks, and 438.3 N after 26 weeks. Time thus showed to have a significant influence on the results. Both the 26-week and the 16-week values were significantly greater than the values obtained at 12 weeks.

A group analysis revealed a significant influence of the different surgical methods on pullout strength. Implants placed in maxillae augmented with bovine hydroxyapatite showed a mean pullout strength (393.0 N) that was significantly greater than that of implants in the negative control group (259.3 N), although not significantly greater than implants placed in sinuses augmented with cancellous bone (356.7 N).

The three treatment groups showed variable increases in pullout strength between 12 and 26 weeks (Fig 4-16). The implants of the group augmented with bovine hydroxyapatite showed the highest pullout strength of all three groups at 12 weeks. After 26 weeks, the pullout strength of implants placed in autogenous cancellous bone was comparable. Both the empty control group and the group augmented with cancellous bone showed a comparably low pullout strength after 12 weeks. However, while the pullout

strength of the empty group increased by 1.6 N per week, that of the group augmented with cancellous bone rose by 21.4 N per week, thus nearly doubling that of the empty control group at 26 weeks.

These results are of special interest with regard to the different healing times required between first- and second-stage surgery in sinus graft procedures. The bone-implant bond formed after augmentation with autogenous cancellous bone did not seem to have the same initial interfacial bond strength as in sites augmented with hydroxyapatite after a healing period of 12 weeks. However, the values of the two augmented groups gradually approximated each other after a healing period of 26 weeks.

In summary, both experimental sinus augmentation procedures led to a significant increase in pullout strength, compared to the nonaugmented control group and comparable implants placed in maxillary cancellous bone, while comparative results of implants placed in compact bone⁶⁸ were not achieved. However, it can be assumed that implants can actually tolerate markedly higher loads, because numerical stress analyses and model experiments have indicated high peak stresses at the bone-implant interface in pullout or push-through tests^{70,71} that result in premature failure and therefore underestimation of the bone-implant bond.

Clinical Consequences

Several factors must be taken into account before a sinus floor elevation is carried out.

Local risk factors

Local risk factors comprise all local pathologic processes and surgical interventions that might result in a change in the normal anatomic conditions. Typical examples are cysts or cystectomies, acute chronic sinusitis, oral surgical procedures, such as surgical tooth extraction, and rare incidents, such as radiation.

Incision technique

The safest method to avoid postoperative fistulas and to preserve the buccal attached gingiva is to carry out a horizontal incision palatal to the alveolar ridge. Any creation of a flap has the disadvantage that the maxillary alveolar process is denuded (Fig 4-17). This fact should be taken into account, especially when a twostage surgical procedure is used. A horizontal buccal incision is therefore a possibility for first-stage surgery.

Preparation technique

The hard and soft tissue to be prepared is often old, brittle, and poorly vascularized. Furthermore, it can be assumed that the maxillary alveolar process lacks a cortical layer for implant fixation in most cases. The local bone should be denuded as little as possible to avoid jeopardizing the local periosteal blood supply to alveolar bone.⁷²

The blood supply to the maxilla is assumed to occur via both centromedullary and mucoperiosteal vessels.⁷³ However, the lateral antral wall consists of very thin compact bone. About 70% to 80% of the arterial blood supply to cortical bone and even 90% to 100% of the venous flow occur via the periosteum.⁷³ This means that the centromedullary vascularization seems to play a minor role in this area. Instead, the lateral antral wall seems to be supplied by the periosteum and dense vascular networks located within the schneiderian membrane. It is therefore all the more important to preserve the periosteum and blood vessels during all surgical interventions in the atrophic maxilla to avoid an impairment of the blood supply to local bone, because any damage to the periosteum can cause necrosis and subsequent resorption of underlying bone as a result of ischemia.⁷³ Especially in severely atrophic maxillae, the alveolar ridge should be denuded as little, as carefully, and as briefly as possible to cause minimal impairment of the blood supply.

The schneiderian membrane has a rather poor nutritive effect. Therefore, its most important task during sinus augmentation surgery is to act as a net for the grafting material. When a small perforation of the schneiderian membrane occurs, the preparation should be continued, because the perforation site is reduced by tissue agglomeration during membrane mobilization or seals up as a result of overlapping mucosal layers.

Augmentation and osteotomy window

In especially large maxillary sinuses that are associated with severe pneumatization of the maxillary alveolar process, more than 10 cm³ of grafting material can be required. Because it does not seem to be possible to obtain this amount from the chin region or other oral donor sites alone, extra oral donor sites or nonautogenous materials must be used. Any osteotomy affecting the maxillary sinus should be as small as possible and should be carried out with the utmost preservation of intra osseous vessels. This applies to both facial fenestration of the maxillary sinus and the Le Fort I osteotomy. Continuous bleeding from endosseous vessels can make the placement of grafting materials more difficult during the operation.



Fig 4-17 Frontal section through the alveolar process in the region of the first molar (anatomic specimen). A classic sinus floor elevation is simulated to illustrate denudation of the maxillary alveolar process.

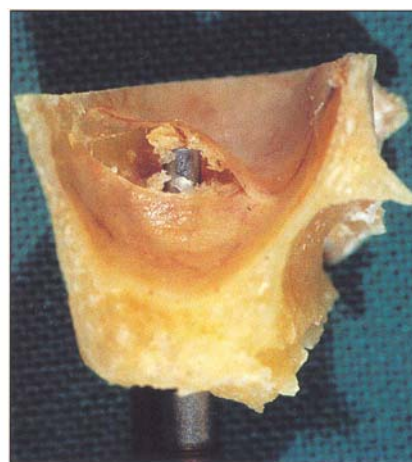


Fig 4-18 Frontal section through the maxillary alveolar process in the region of the second molar (anatomic specimen). The schneiderian membrane has been elevated from the occlusal aspect, via the prepared implant host site, and has been torn.

Because of the local conditions, elevation of the schneiderian membrane from the occlusal aspect, via the prepared implant host site, seems to be possible only in mildly atrophic alveolar ridges. When attempts are made to displace the schneiderian membrane further cranially, tearing of the membrane is very probable (Fig 4-18) and may result in penetration of grafting material into the maxillary sinus.

Healing period for the graft

Because severe atrophy results in an unfavorable vascularization of the maxillary alveolar process and the adjacent maxillary sinus, the grafting material should be allowed to heal 1 to 2 months longer than normal.

Positioning, uncovering, and loading of implants

Because of the reduced trabecular density and connectivity in the maxillary posterior region and the comparatively low percentage of bone-implant contacts, a rather large number of implants, which should be positioned as axially as possible (analogous to the roots), is necessary to transmit masticatory forces. For the same reason, patients suffering from bruxism should be considered risk patients.

When implants are uncovered, markedly thicker soft tissue layers are present palatally to the alveolar ridge, and extensive soft tissue excision should be carried out to create ideal hygienic conditions.

Because of the initially small number of boneimplant contacts, progressive loading of the implants should be contemplated to give the bony host site sufficient time for adaptation and bone apposition.

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Treatment Planning for Sinus Grafts

Ole T. Jensen, DDS, MS

Treatment planning for dental implants must be based on prosthetic considerations and, in all but the most simple cases, should involve a complete dental restorative workup. In most cases, this will minimally involve the following:

1. Facebow-mounted, articulated casts placed in centric relation
2. Diagnostic waxup
3. Presurgical equilibration or restorative measures
4. Surgical stent manufactured by using a surveyor
5. Radiographic or computerized tomographic verification

The more complex the dental restorative treatment, the more important these steps become. In most cases, the non-implant-supported restorative needs should be attended to first, especially in instances of a disturbed occlusal plane such as a reverse curve of Spee or bite collapse.¹⁻³ Anterior guidance should be established.⁴ Orthodontic leveling and aligning may be required prior to implant placement, and tooth size and space discrepancies need to be discerned.⁵ Presurgical equilibration may be needed to optimize the occlusion.⁶

Endodontic and periodontal treatment should also be taken into account/⁷ Genetic screening for interleukin-1 (11-1) may be considered in highly periodontally compromised dentitions.⁸

The sinus should be evaluated as part of the initial workup not only to determine sinus health but also to assess sinus location in relation to implant placement (see Chapter 4). A general goal would be to place an optimal number of implants, but with the least amount of sinus intervention required to do the job. Consider

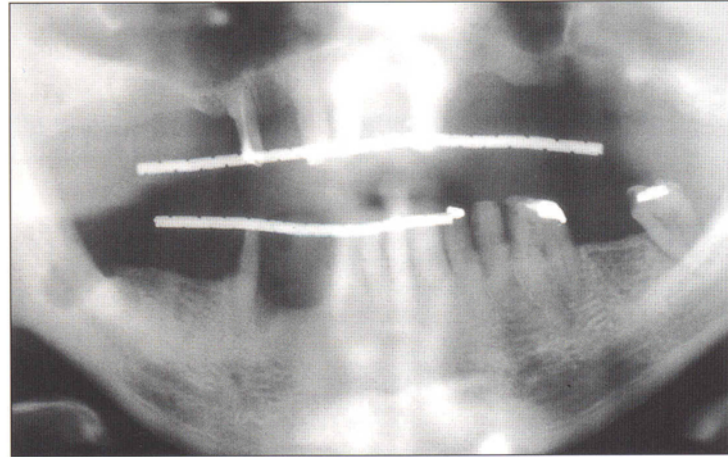
ing that sinus complications (although rare) can lead to severe medical compromise, surgical intervention in the maxilla should be reasonable and necessary and never cavalier.^{9,10}

Sample Case

Figures 5-1a and 5-1b show the preoperative occlusion of a 60-year-old patient for whom dental reconstruction was done. He had fractured his mandible many years earlier and presented with a Class III malocclusion with unilateral cross bite resulting from malunion of the fracture. Several teeth had been lost over the years, and he presented with a severely compromised dentition.

After extraction of several posterior teeth, mounted casts were made, and a diagnostic waxup was done to help select a final treatment plan. After an implant restorative approach was selected, a guide stent was made from a suck down model over stone casts made from the diagnostic waxup (Figs 5-1c and 5-1d). A surveyor was used to vertically position guide holes at proper angles (Fig 5-1e). Brass tubing was used in 2 and 3-mm diameters and then telescoped (Fig 5-1f), positioned, and luted to the guide splint with the aid of the surveyor to assure proper angulation (Fig 5-1g). Implants were planned in the mandibular arch also (Figs 5-1h and 5-1i). The brass tubes passed through the occlusal surface of the stent and into the cast as near as possible to the desired center of the alveolar crest.

Positioning is verified using panoramic and periapical radiographs. As an additional step to correlate



Figs 5-1a and 5-1b Preoperative malocclusion of 64-year-old patient who had malunion of a mandibular fracture and loss of multiple teeth. (Courtesy of Dr Curtis Becker.)

Figs 5-1c to 5-1i Measures used to establish a surveyor-oriented guide stent. Brass tubes are embedded in the acrylic stent for use as a surgical guide.



Fig 5-1c



Fig 5-1d



Fig 5-1e



Fig 5-1f



Fig 5-1g



Fig 5-1h

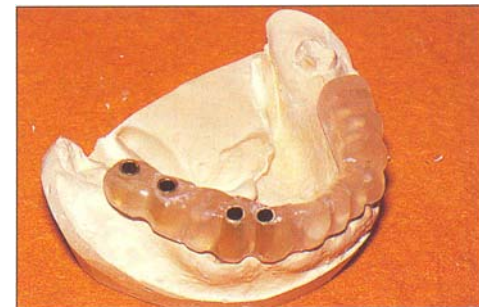


Fig 5-1i

Figs 5-1j to 5-1m Final results of restoration 2.5 years after completion.

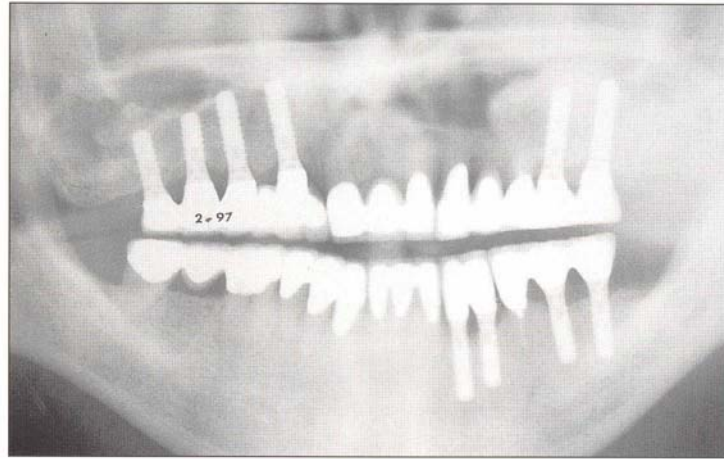


Fig 5-1j

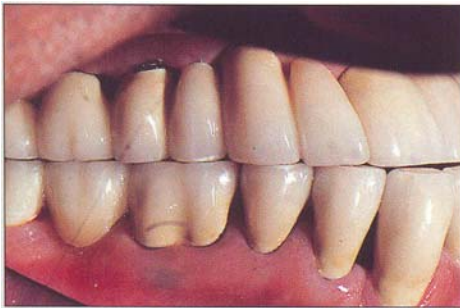


Fig 5-1k



Fig 5-1l



Fig 5-1m

the guide stent, a computerized tomographic scan or tomographic image can be made. This may be especially valuable for the novice in sinus grafting procedures. The significance of these images should not be overemphasized, however, because it is more important to place the implant at or near the guide stent site or, if it is not possible to place the implant in that location, to prepare the site with bone grafting for future placement. The occlusal stent, which is based on the diagnostic waxup, is more important to treatment than a computer-generated image.

Figure 5-1j shows the final radiograph, taken approximately 2.5 years after final restoration. Iliac bone graft was used for sinus grafting. The final restorative scheme (Figs 5-1k to 5-1m) improves on the preoperative finding. Each implant was placed to emerge through the occlusal surface. A sufficient number and length of implants were used. The final restoration addressed the Class III-crossbite situation with a well-distributed and balanced occlusion to obviate the need for orthognathic surgery.

This result would have been almost impossible to accomplish without a diagnostic waxup-derived oc-

clusal guide stent, because it becomes too easy for the surgeon to get lost in the midst of the reconstructive surgery effort when there is bone graft mortising of both the alveolus and the sinus. If there is no surgical guide to use during surgery, the surgeon may mistake the alveolar relation, the occlusal plane, or the anteriorposterior or transverse jaw relationship. When these are ignored, poorly distributed or angled implants result in angled and cantilevered dental restorations, which may compromise the integrity, and therefore the longevity, of the final restoration.

Strategy for Treatment Planning

Complex treatment plans can be undertaken by using a simple strategy to work up the case. This orderly approach to treatment planning of the sinus graft case compromises three variables:

1. Assessment of the presurgical osseous bed
2. Assessment of the alveolar relation
3. Development of the final prosthetic restorative plan

Assessment of the presurgical osseous bed

The presurgical osseous bed determines the type of graft that should be used, whether implant placement should be delayed or simultaneous, and whether other procedures, such as sinus endoscopy or hyperbaric oxygen therapy, should be employed preoperatively.¹¹⁻¹⁴

Some finite volume of bone is needed as a base for an osseous bed to enable incorporation of the graft. A free bone graft placed without any contact to native bone will be nonfunctional and eventually resorb. If there is a fibrous junction between the graft and the osseous bed, consolidation will not occur, and the graft will not be secure enough for the placement of osseointegrated implants.¹⁶ Highly resorbed areas, where the available preoperative bone is 1 or 2 mm or perhaps is dehiscenced or even absent, can be effectively treated with iliac bone graft and delayed implant placement.¹⁷ Although many case reports suggest that implants can be placed simultaneously in such cases, it is, by and large, an extraordinary effort that has an attendant higher implant failure rate, provides significantly less optimal indications for implant placement, and is subject to a higher risk for graft failure¹⁸ (see Chapters 10 and 11).

On the other end of the spectrum is the case in which the floor of the sinus is 6 to 10 mm, the width is good and bone quality is firm, and, perhaps, the patient is younger with teeth anterior (or posterior) to the area to be implanted. In this case, the practitioner could choose to elevate the sinus membrane through the osteotomy site of the implant itself with an osteotome or a small instrument in order to place a 13- to 15-mm implant in a simultaneous fashion with little or no graft placement at all (Figs 5-2a to 5-2e). Figure 5-2a shows the preoperative situation, when only one implant could be placed without incursion into the sinus. There was approximately 6 to 7 mm of residual bone, which was approached via an osteotome technique.¹⁹⁻²¹ The implants were stable enough to have exposed cover screws (Fig 5-2c). Six months later, a three-unit restoration was made. The sinus osteotome technique is shown in sequence in Figs 5-3a to 5-3f.

Each case is individual. The judgment of the clinician on how to approach the sinus graft is paramount. The experienced clinician may know what can't be gotten away with in any given case; however, guidelines are useful in keeping the practitioner on a path that will most likely be successful. No one technique can be used

for all sinus graft situations and the surgeon should not try to use the same technique, for example, hip graft harvesting, in every case.

Classification of implant sites

Figure 5-4 presents a site classification that can be used to establish the parameters by which one form of treatment is suggested over another (see also classification of anatomy, Fig 4-2, page 34):

- Class A: 10 mm or more of residual bone present (100% of a 10-mm implant in native bone)
- Class B: 7 to 9 mm of residual bone present (70% to 90% of a 10-mm implant in native bone)
- Class C: 4 to 6 mm of residual bone present (40% to 60% of a 10-mm implant in native bone)
- Class D: 1 to 3 mm of residual bone present (10% to 30% of a 10-mm implant in native bone)
- Class E: Absent or ablated sinus

This rather arbitrary site classification is intended to help suggest the appropriate grafting material or grafting technique to use, based on a specific site. However, adjacent sites can have disparate site classifications, and it is impractical to use different grafting materials in such cases. So, the practitioner must consider whether the overall sinus morphology is class C or class D, for example, in selecting a grafting material.

It is useless to use the osteotome technique for simultaneous implant placement in a site if a few millimeters of bone is available. A lateral approach is better in that instance, and a graft should be used.

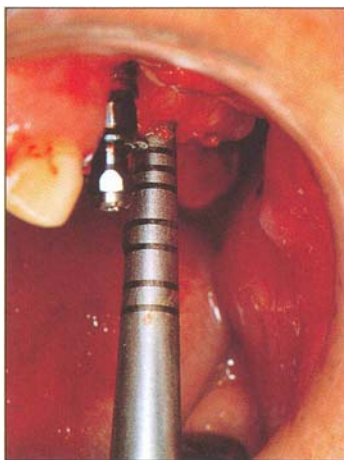
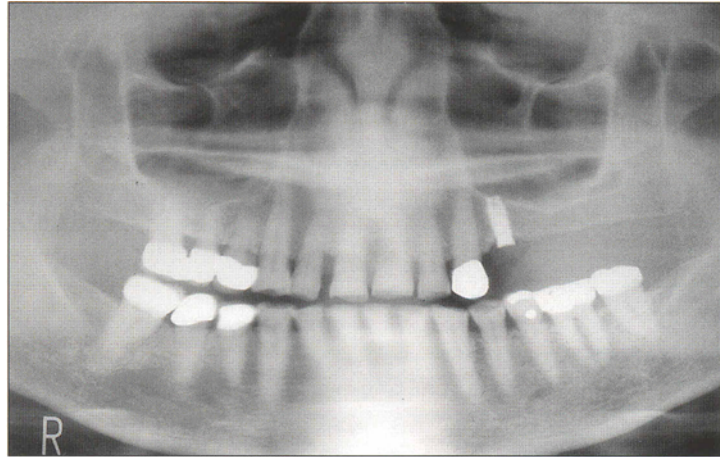
The site classification is based on a vertical bone measure and does not take into account the horizontal measure. However, analysis of how much of a 10-mm implant, by percentage, is inserted into native (nongrafted) bone indicates the merits of differentiating between a site that might be only 10% in native bone and one that is 90% in native bone.

Treatment of implant sites by class

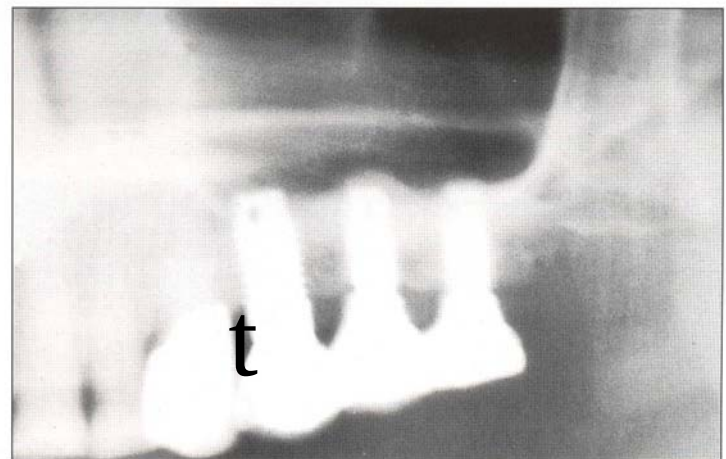
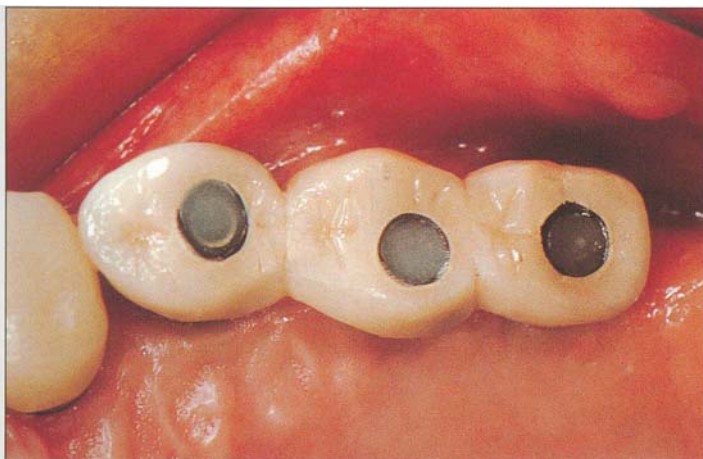
In accordance with using this simple classification but yet, once again, deferring to the surgical judgment of the practitioner, the following materials and techniques are suggested for the various site classes (see also classification of anatomy, Fig 4-2, page 34):

- Classes A and B: Osteotome technique; simultaneous approach; exposed cover screws
- Class C: Lateral approach with a barrier membrane; simultaneous (submerged) or delayed (submerged) approach; autogenous graft, alloplastic graft, allograft, or xenograft
- Class D: Lateral approach (possibly Le Fort I approach); autogenous grafting (tibial, calvarium, ilium, maxillofacial); delayed approach; submerged cover screws

Fig 5-2a Class *CIS* case in which 6 to 8 mm of residual bone is found preoperatively. (Courtesy of Dr Richard Lazzara.)



Figs 5-2b and 5-2c A crestal osteotomy approach intrudes bone into the sinus, allowing for the placement of 10-mm implants.



Figs 5-2d and 5-2e A final restoration and radiograph reveal stability 1 year after the final restoration.

Figs 5-3a to 5-3f The sequential steps for using the osteotome technique are illustrated, going from small- to large-diameter osteotomes and gradually intruding the sinus floor. In Figs 5-3d and 5-3e, a small amount of autograft is intruded into the sinus to help maintain space for later (or immediate) implant placement.



Fig 5-3a

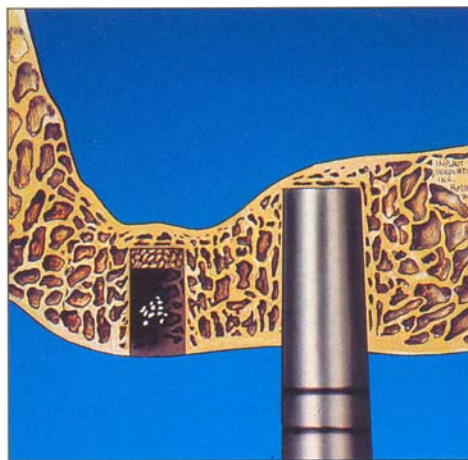


Fig 5-3b



Fig 5-3c



Fig 5-3d



Fig 5-3e

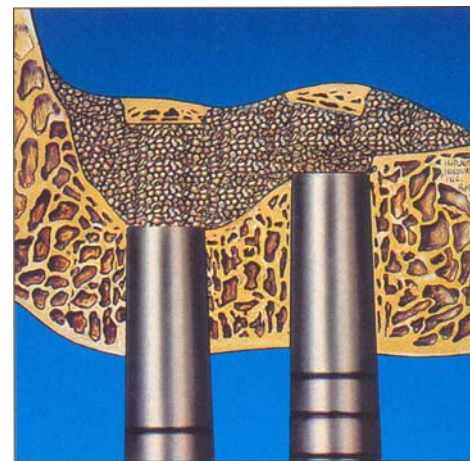


Fig 5-3f

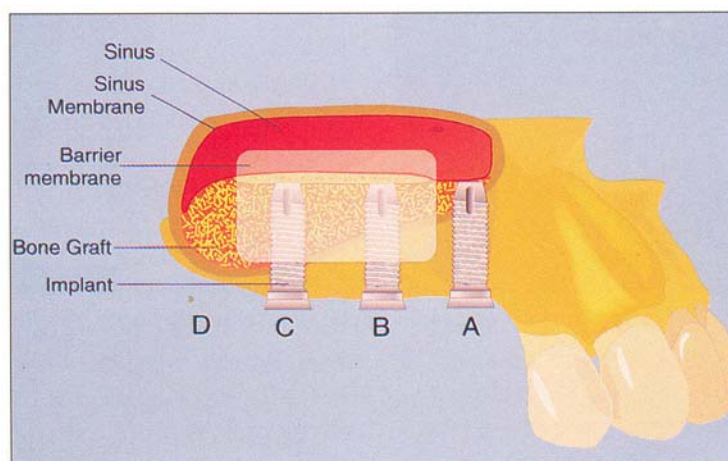
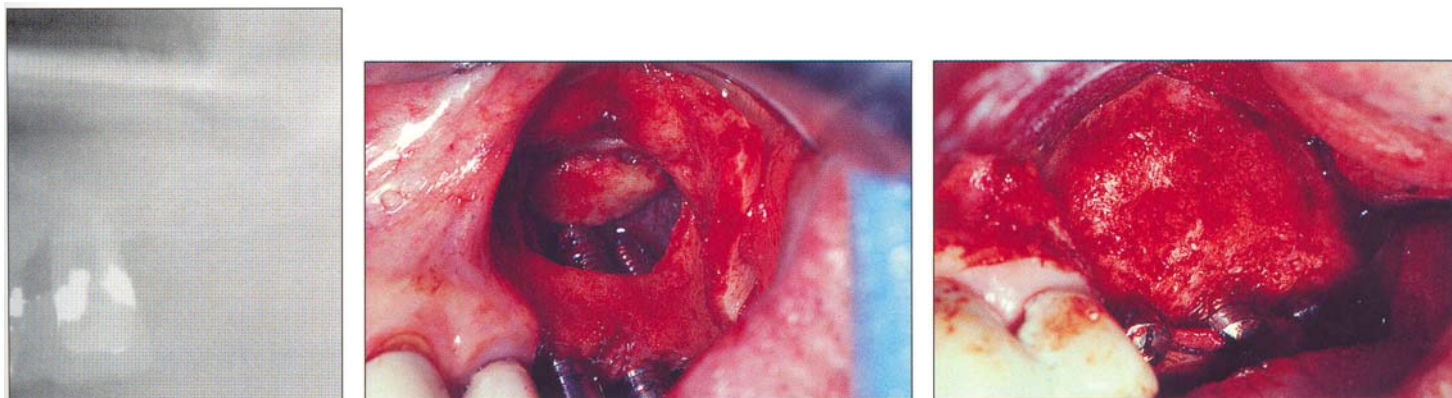
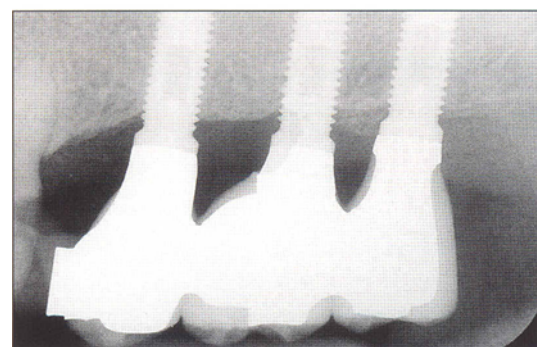


Fig 5-4 Site classification to aid in communication and treatment planning. Where less than 6 mm is present, the utility of a crestal approach is much diminished, and a lateral approach is better. Also, a class B or class A case is better for immediate placement situations, while a class CorD site is better suited to a delayed approach.



Figs 5-5a to 5-5c Class C case treated with allograft, immediate placement, and ePTFE over the window.

Fig 5-5d Follow-up radiograph taken 9 years postrestoration. (Courtesy of Dr Donald Nassimbene.)



This treatment regimen advocates the use of autogenous bone in proportion to the severity of loss of preoperative bone stock. Also, there is a tendency to use the delayed approach as the native bone level decreases.

These recommendations also address the issue of whether or not to submerge an implant or place highprofile cover screws to avoid second-stage surgery. If implants are left exposed, there has to be sufficient fixation, ie, preoperative bone stock, present to warrant this technique. The failure rate will be higher in exposed implant cases where there is insufficient bone to overcome the forces of a soft diet transmitted through a softlined overdenture during the demineralization phase.

This protocol is still empirical and needs to be verified to become valid but has some documented evidence based on the Sinus Consensus Conference findings of 1996 and one review of extremely atrophic maxillae treated with and without simultaneous implant placement and iliac grafting (see Chapter 19).

The class C site, which has about 5 mm of bone present, is frequently treated with a lateral approach and has been successfully treated via numerous grafting and implant placement protocols²²⁻²⁴ (see also Chapter 7). Figures 5-5a and 5-5b show a patient prior to tooth extraction and then at surgery, where bone grafting and implant placement were performed simultaneously. Allograft was used and an expanded polytetrafluoroethylene (ePTFE) barrier membrane was placed over the

grafting site. Figure 5-5c shows the exposure findings. Restorative measures included a screw-retained fixed partial denture. Figure 5-5d shows long-term follow-up stability of both implants and the graft, 8 years later.

Figures 5-6a to 5-6f show a class C case, for which a combination of autograft and allograft was used in a delayed approach. Implants were placed 7 months after grafting, and then restored 8 months later with a fixed prosthesis.

Assessment of the alveolar relation

The use of grafting materials based on host bone availability (and vitality) is not the only concern in treatment planning. The residual alveolar relation is an important factor as well. The alveolus can be resorbed vertically, horizontally, or both, but can also be orthognathically malaligned. In most instances, the question of concern is one of vertical deficiency. At some point, the vertical loss becomes so great that vertical augmentation is needed to prevent excessive vertical cantilever. If there is an unfavorable implant-crown ratio, efforts should be made to make the implant-crown ratio at least 1 to 125 (Figs 5-7a and 5-7b).

If there is transverse deficiency, the horizontal (lateral) cantilever can become excessive for hardware components or implant stability with sinus grafting

Figs 5-6a to 5-6f Class C case where a combination of autograft and allograft was used in a delayed approach. Implants were placed 7 months after grafting and then restored 8 months later with a fixed partial denture. (Courtesy of Dr Carl Brownd.)

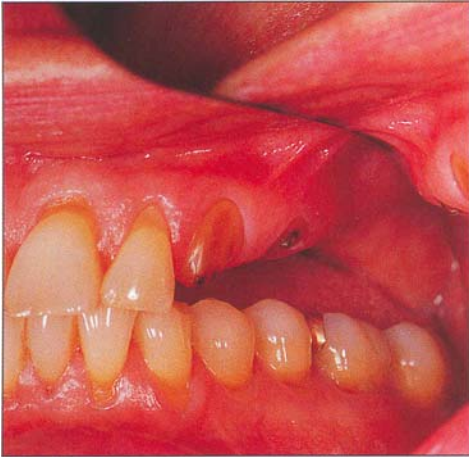


Fig 5-6a



Fig 5-6b

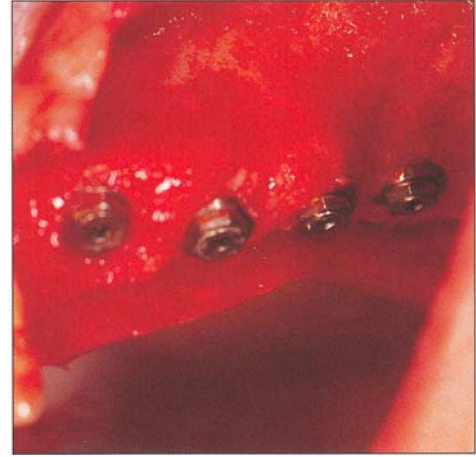


Fig 5-6c

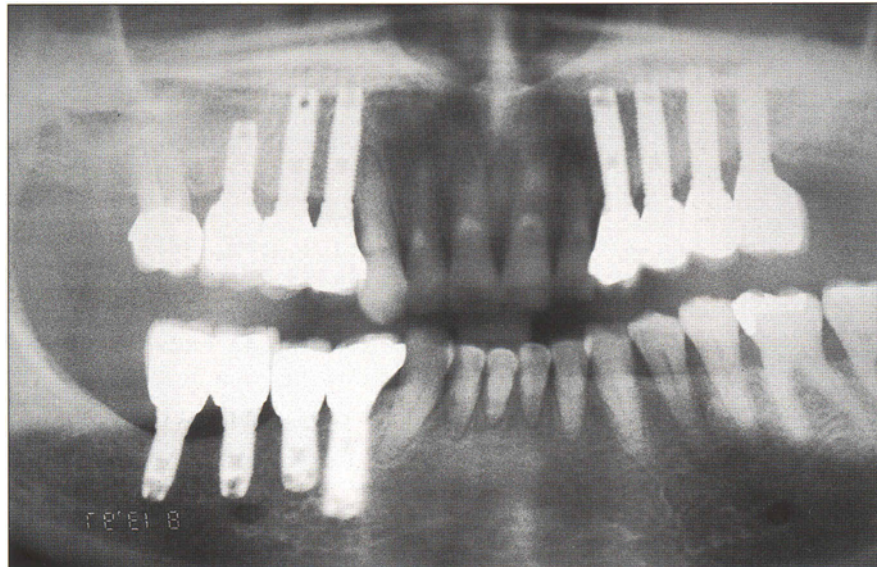


Fig 5-6d



Fig 5-6e

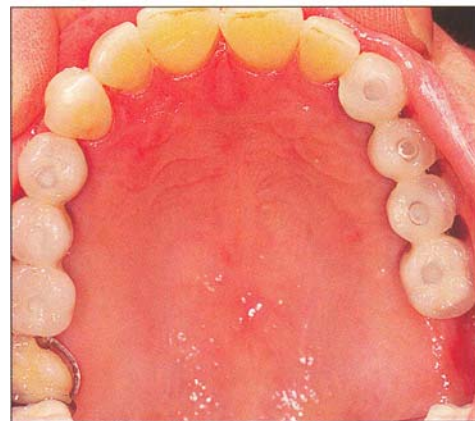
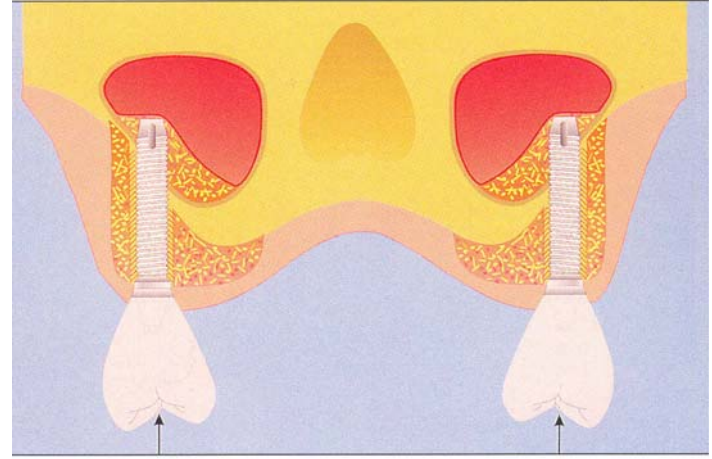
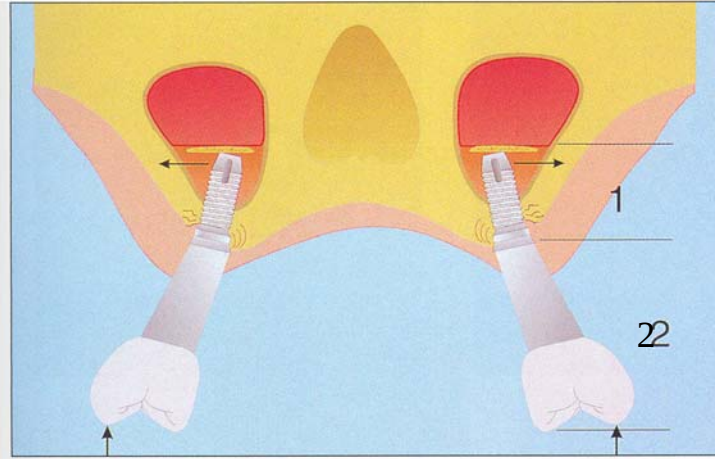


Fig 5-6f

alone²⁶ (Fig 5-7c). If the diagnostic waxup demonstrates an excessive horizontal cantilever, lateral grafting (usually lateral or vertical augmentation grafting or both) is indicated, or an overdenture approach is suggested.

When there is severe transverse deficiency, the sinus graft turns into a nasal graft or combined nasal and

sinus graft! (Fig 5-8a). A decision has to be made whether to angle the implants or graft the sinus and alveolus laterally to improve the implant position (Fig 5-8b) (see Chapter 14). In these highly resorbed maxillae, the alveolar process is essentially absent or can reside directly over the nasal fossa, and the approach to



Figs 5- 7a and 5- 7b An unfavorable implant-crown ratio can be corrected by alveolar vertical grafting to approach a 1: 1 ratio.

Fig 5-7 c Lateral cantilever can lead to component failure or debonding of osseointegration because of unfavorable bending moments of force.

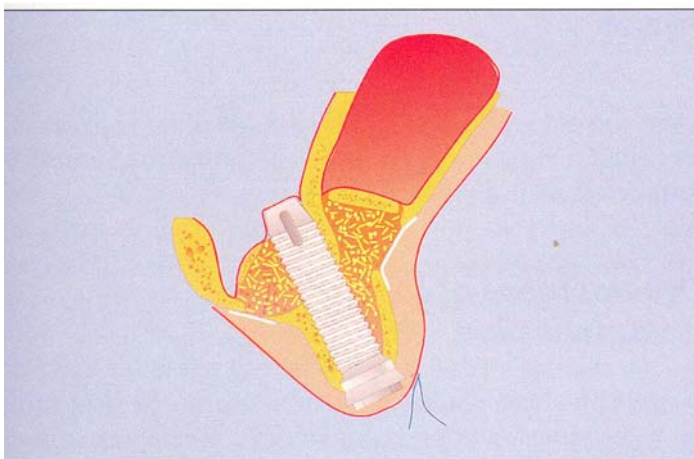
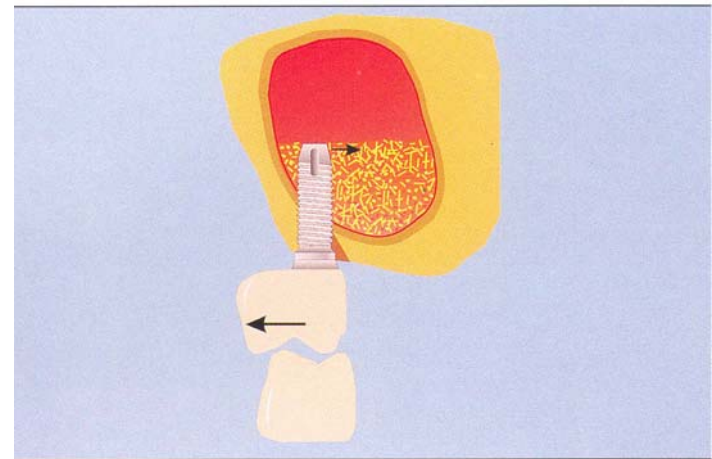


Fig 5-8a In severe transverse maxillary alveolar deficiency, nasal floor grafting may improve stability of the implant, but the implant angulation can be unfavorable.

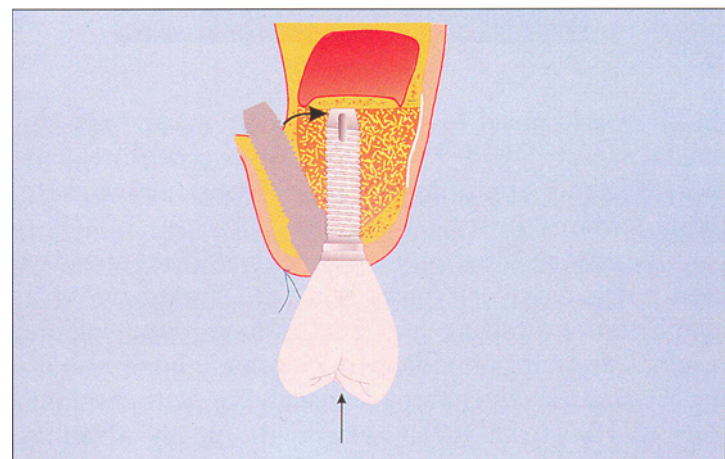


Fig 5-8b The angle of implant emergence can be improved by alveolar augmentation.

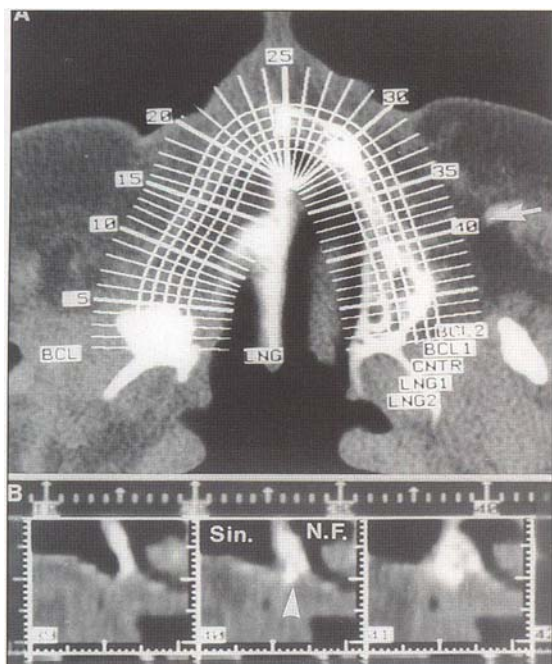


Fig 5-9a



Fig 5-9b

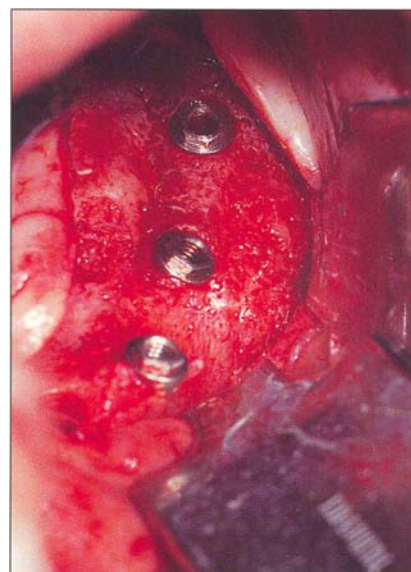
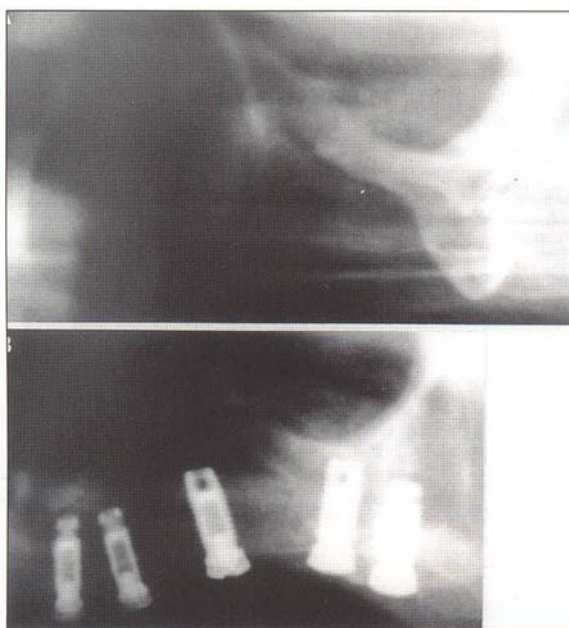


Fig 5-9c



Figs 5-9a to 5-9d A palatal and lateral approach is used to graft both the sinus and the nasal fossa in a highly compromised (and hemimaxillectomized) patient. In Fig 5-9a, note that the alveolar crest lies exactly over the nasal wall medial to the sinus cavity (arrow). (Courtesy of Dr Scott Perkins.)

Fig 5-9d

the sinus and nasal fossa can be easily made from the palatal aspect (Figs 5-9a to 5-9d). An overdenture is indicated in this situation, or major reconstructive grafting procedures must be undertaken.²⁷

One unique situation is the hemimaxillectomized or even total maxillectomized patient. Treatment with augmentation grafting and barrier membranes on the residual slivers of maxillary or zygomatic bone bordering the sinuses can enable reconstruction with implants (Figs 5-10a to 5-10f). Even without an alveolus, implant-supported prostheses can be made with judicious bone grafting; however, an explicit awareness of where the restored occlusal plane and ideal alveolar

bone locations, ie, the prosthetic alveolus, is necessary for the surgeon to establish a functional implant-supported dental restoration.

Development of the prosthetic treatment plan

Despite the best planning and the use of the best surgical techniques and optimal materials, osseointegration is not a certainty; therefore, any presurgical treatment plan is always prospective. Prosthetic restoration on implants, despite an excellent track record, should not be

Figs 5-10a to 5-10f A near total maxillectomy is treated with lateral sinus wall guide bone graft augmentation with immediate implant placement in the zygomatic buttress and then restored with a bar-clip obturator denture. This restoration functioned 3 years before recurrence of nasopharyngeal carcinoma led to the death of the patient. (Courtesy of Dr Scott Perkins.)

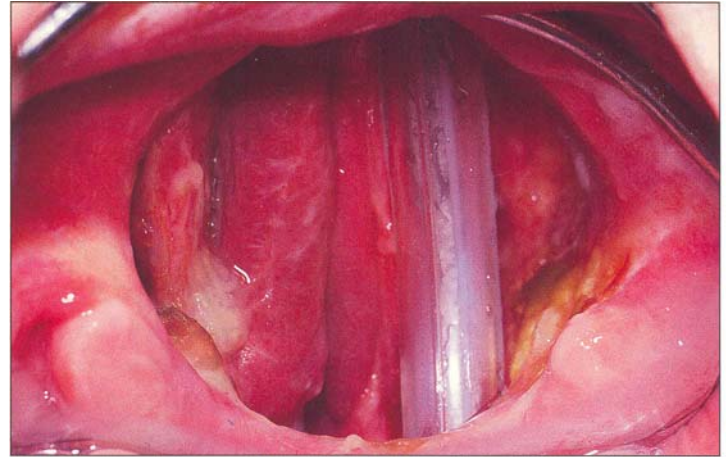


Fig 5-10a

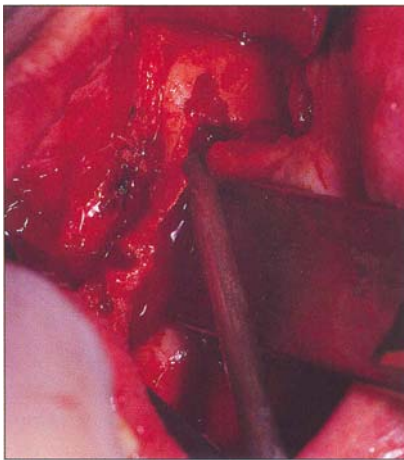


Fig 5-10b

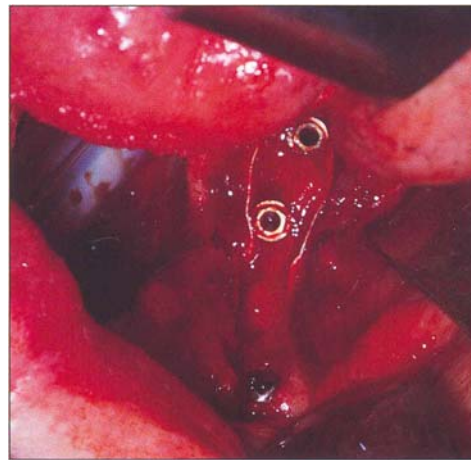


Fig 5-10c

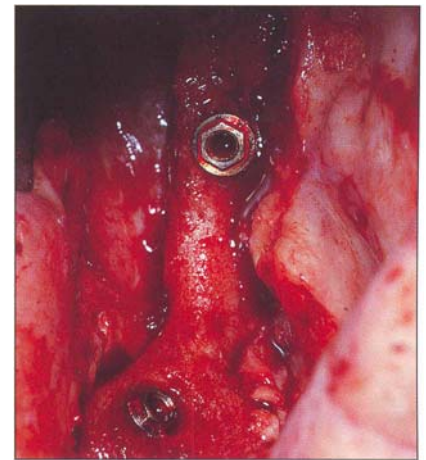


Fig 5-10d

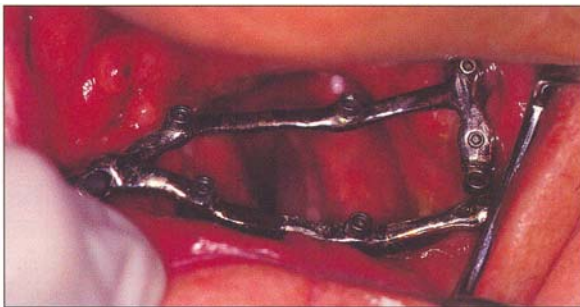


Fig 5-10e



Fig 5-10f

viewed as the only viable approach to dental restoration of the oral cavity. Great care, even hesitation, should be exercised before compromised teeth are condemned to extraction and implant replacement. A compromised tooth abutment is better than a nonosseointegrated implant or an infected or failed bone graft. Surgery of the sinus cavity, although well documented as having minimal complications and a very high 5-year success rate, is still a bold treatment-planning option to choose when teeth are present in the area and could still be treated by conventional conservative means. In general, it is better to defer extraction of teeth until their condition is hopeless than to subject the patient to a failed treatment sit

uation in which the patient is worse off than when he or she started.²⁸

Conversely, treatment planning for sinus grafting and implants, where compromised teeth still remain, should take into account the natural history of the patient's dentition and periodontal status as well as the option to extract teeth prior to complete loss of the supporting bone. The concept is to remove teeth prematurely in a definitive move when the overall care of the mouth necessitates it, for example, when a posterior implant-supported restoration is placed to help save anterior compromised teeth.²⁹ The preservation of some bone at the floor of the sinus probably improves the

prognosis for implants. When 8 mm of bone is available in the posterior maxilla and implants are placed in conjunction with sinus grafting, implant failure is rare³⁰ (see also Chapter 19).

Here then, is a view opposite the one expressed earlier. If bone is needed for implant osseointegration, why not extract early to preserve bone and improve the chances for the long-term final restoration with implants rather than nurse along a compromised, diseased dentition that will eventually be lost anyway? To frame the question even more radically, why not remove one tooth anterior to the sinus, especially if it is periodontally compromised, to use as a non-sinus-directed implant site to splint to the sinus-directed implants to strengthen the overall restoration? These questions become serious issues that should be approached in consultation with the entire treatment team and with complete informed consent by the patient.

The current regenerative possibilities for salvage of compromised teeth must be balanced by the projected eventual treatment goal. If this involves implants and sinus grafting, strong consideration should be given to removing teeth prior to complete loss of all available bone at the sinus floor, a situation in which a higher failure rate of implants can occur, even when iliac grafting is performed. Also, as advocated earlier, when there is at least an overall class C or class B situation, local maxillofacial bone, allograft, or xenograft can be used with great success. So, there may be less morbidity in the surgical treatment, ie, local graft harvesting, when at least 5 or 6 mm of bone residual has been preserved by an early extraction.

Sample Treatment Plans

The practice of dentistry cannot be one of formulas and protocols so rigid that the inability to diverge from a certain standard locks out appropriate care for the patient. Experienced clinicians who seek specialist consultation when needed help the patient to make an informed decision on appropriate care for his or her mouth. The following treatment plans and clinical examples are suggested as guidelines that may apply to most sinus-directed implant restorations. These treatment plans are based on current technology with the various available implant systems and are certain to undergo modification as implant technology improves in the future.

Single-implant sinus graft

The single implant that extends into the sinus becomes more difficult to do and probably has a less certain prognosis the more posteriorly it is placed in the arch

(Figs 5-11a to 5-11c) and the less preoperative bone is available³¹ (Figs 5-12a to 5-12d). Another factor that can effect the prognosis is adjacent teeth. The presence of teeth on either side of the single-implant restoration is favorable (Figs 5-13a to 5-13d).

The recent advancement of wider implants has made the use of single molar implant in the maxillary arch more likely to be successful³² (Fig 5-14). In general, the second molar single implant is not suggested as a restorative need, and there are few reports in the literature of single maxillary second molar implants. Single maxillary first molar implants also are rarely reported but can be used as a terminal unit or when a second molar is still present. The option of a fixed partial denture should strongly be considered, however.

At least 5 to 7 mm of bone should be available for a single implant to be placed in the molar area in a simultaneous fashion. A delayed approach, especially in the molar areas, is favored, as is a submerged approach. The provisional restoration should not load the implant site during healing, or osseointegration will be compromised.

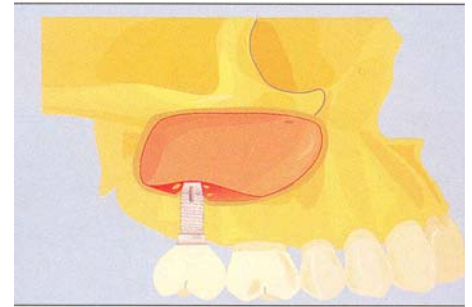
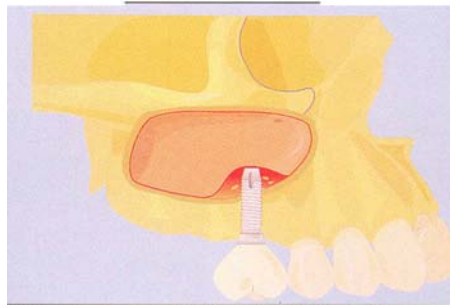
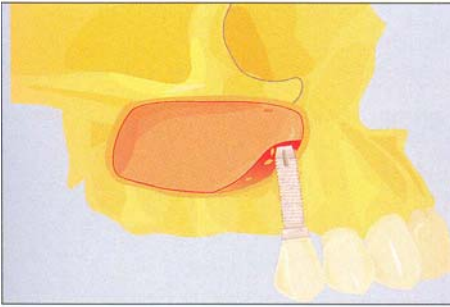
The single crown should be restored with a narrow table and lingualized occlusion.³² An acutely angled implant with an angled restoration (Fig 5-15a) could fail under the load of molar occlusal forces, as could an implant placed in deficient bone³² (Fig 5-15b). These implants must be placed with a guide stent that takes into account the ideal placement angle but are generally not recommended because of the extensive surgery required and the relatively unknown prognosis.

Two-unit sinus-directed restorations

When two implants can be placed there is immediately greater confidence that the restoration will be stronger and more viable. Indeed, one way to treat a missing maxillary second molar is to place two implants in the second molar or pterygoid area (Fig 5-15c). However, in general, a single implant should be placed for every missing tooth to be restored when sinus grafting is performed.

A single unit should not be expected to cantilever a second crown either anteriorly or posteriorly. The implants should be placed in concert with similar angles and in centric tooth position according to the guide stent. The implants should be splinted unless a significant amount of preoperative bone is available, such as in a class A or B site (Fig 5-16).

When there is a class C site, a delayed placement protocol should be considered. Class D sites should have a delayed protocol with a submerged cover screw technique. In general, if only one or two units are placed in a class D site, mandibular bone grafting is used because the quantity of bone needed may not require harvesting bone from the tibia or other extrane



Figs 5-11a to 5-11c Single implants as terminal units in the maxilla probably have a better prognosis the further anterior in the arch they are used.

Figs 5-12a to 5-12d Single implants that encroach on the sinus probably have a better prognosis the less grafting required; that is, they will be more likely to integrate if more natural bone is available, given that the quality of the bone is sufficient.



Fig 5-12a

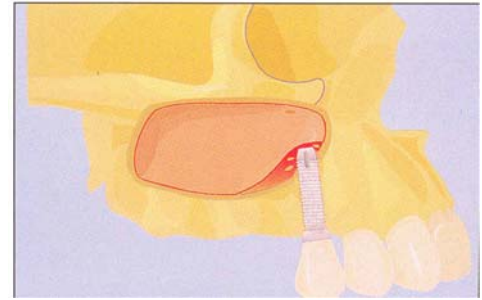


Fig 5-12b

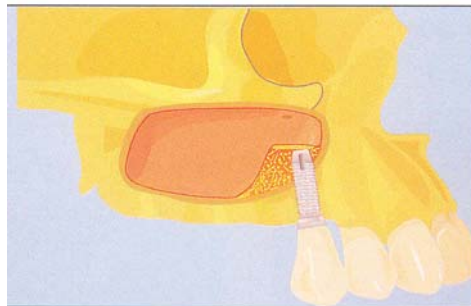


Fig 5-12c

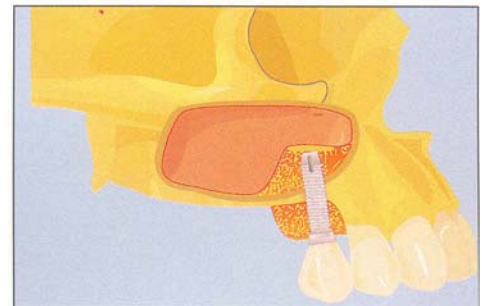


Fig 5-12d

Figs 5-13a to 5-13d Single implants that are not terminal or isolated units will probably have a better prognosis because of load sharing with the dentition.

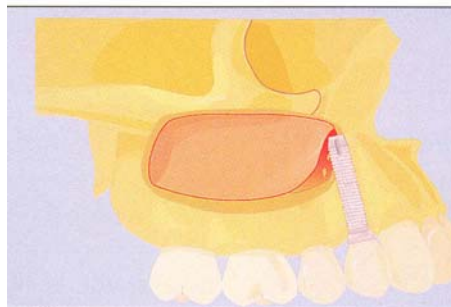


Fig 5-13a

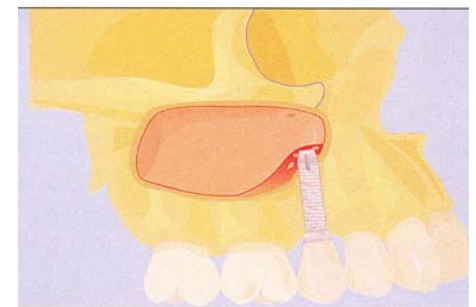


Fig 5-13b

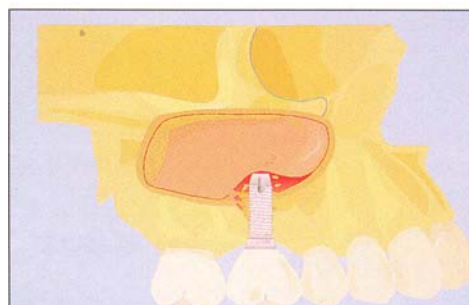


Fig 5-13c

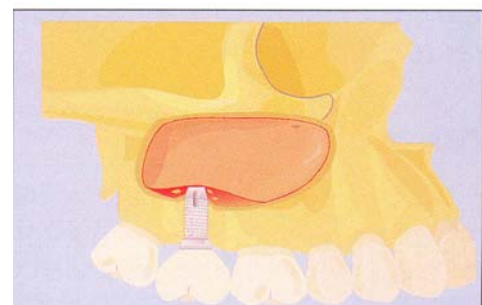


Fig 5-13d

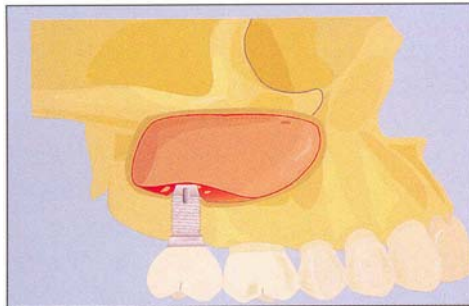


Fig 5-14 Wide implants may be better for maxillary molar positions, although longterm studies are lacking.

Figs 5-15a to 5-15c Strategies to place implants in the maxillary second molar position may require measures that exceed a reasonable cost/benefit ratio.

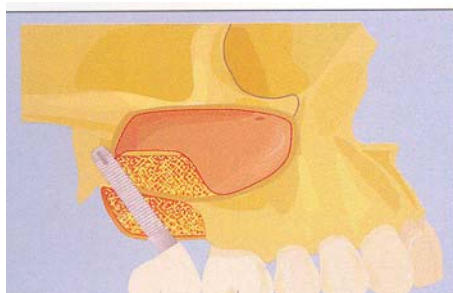


Fig 5-15a Extensive sinus augmentation.

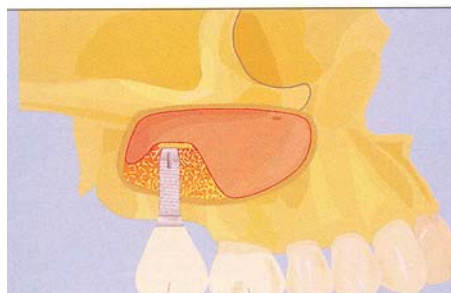


Fig 5-15b Pterygoid plate stabilization with or without sinus grafting.

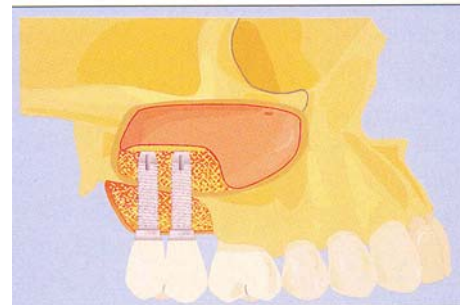


Fig 5-15c Double implant placement with sinus or alveolar grafting or both.

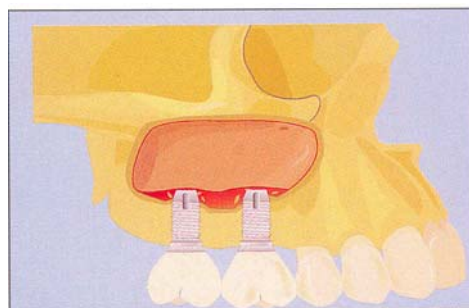


Fig 5-16 Generally, implants placed in the sinus should be splinted together unless it is a class A site and bone quality is excellent.

ous source. When mandibular bone is not used, the tibia is best used with combined augmentation of the sinus floor and the alveolus using ePTFE as a barrier membrane; this is the most certain way to restore to an anatomic alveolus in a highly compromised site.

Three- or four-unit sinus-directed restorations .

Class A or B sites

A typical sinus graft scenario is one in which only the canines and incisor teeth are present. These settings can be highly variable. Some cases can be approached with very little sinus grafting and simultaneous implant placement, while others, if bilateral, may require a large

quantity of iliac, tibial, or calvarial bone to reconstruct the jaw adequately for the implants to be placed in a delayed fashion.

Figures 5-17 a to 5-17 e show a Class NB sinus elevation where only a blood clot with barrier membrane was used. This demonstrates the capacity for at least a limited amount of bone formation from the sinus floor. This is only recommended for a class A or B site (Figs 5-17f and 5-17g). Figures 5-18a and 5-18b show another clinical case in which very little sinus grafting was done. The implants were placed in a single-stage approach using allograft and an ePTFE barrier membrane laterally.

Class C sites

Class C sinus cases treated with three or more implants have numerous documented approaches using various

Figs 5-17a to 5-17c Class A/B sinus elevation in which no grafting was performed. A lateral window and sinus membrane elevation were used, and space was maintained by immediate implant placement and lateral ePTFE placement. (Courtesy of Dr Brian Brada.)



Fig 5-17a

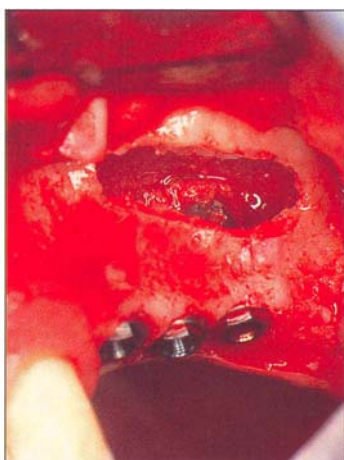


Fig 5-17b

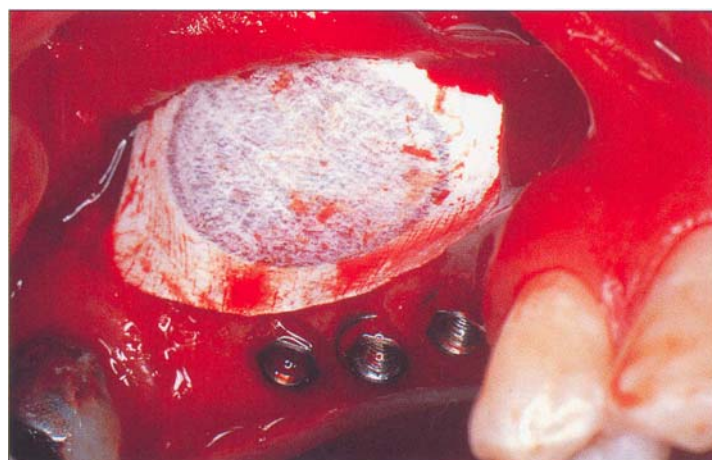


Fig 5-17c



Fig 5-17 d At 4 months, mineralization ensues.

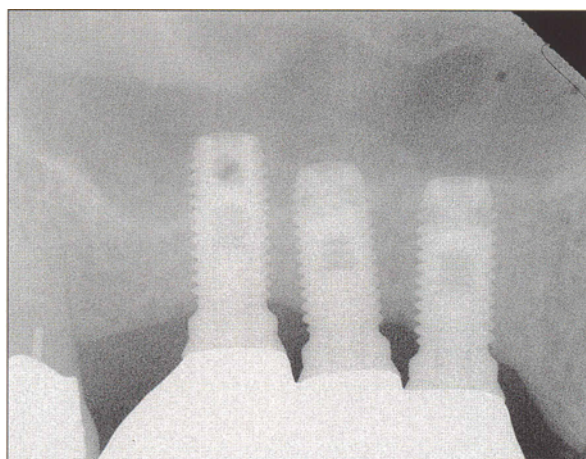
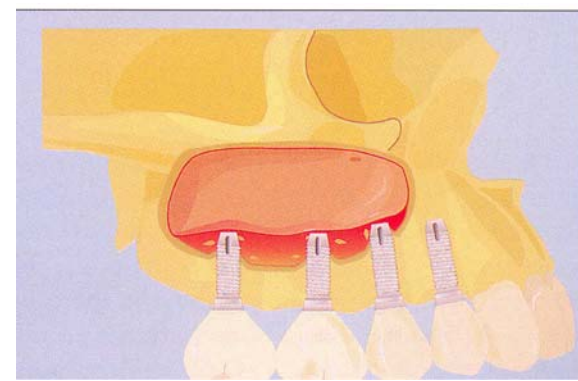
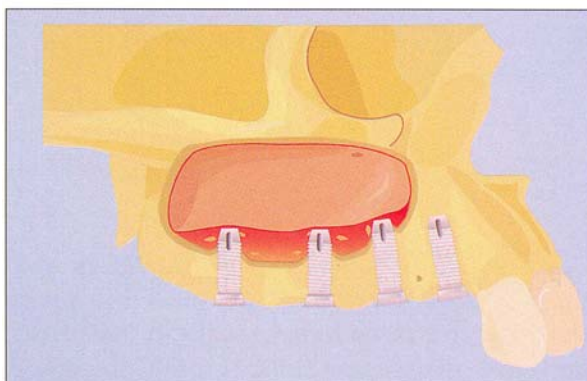


Fig 5-17 e Four years postrestoration.



Figs 5-17f and 5-17 g Minor sinus elevation of only a few millimeters can develop bone without graft material. The lateral window size should be minimal or an alveolar approach should be attempted.

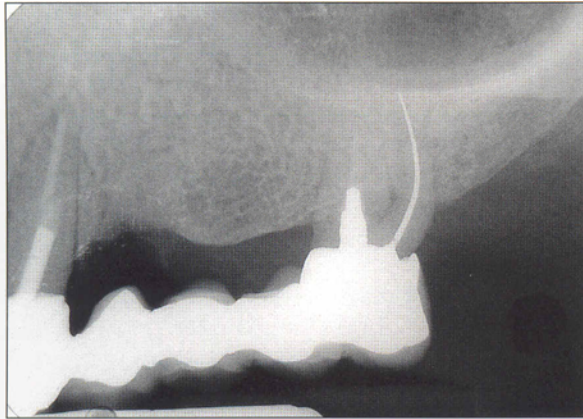


Fig 5-18a Another clinical case in which very little sinus grafting was performed.

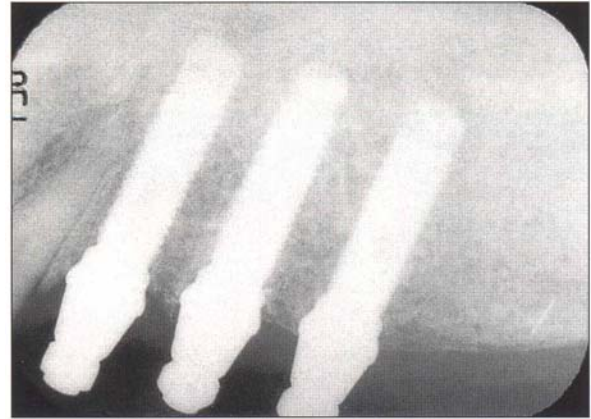


Fig 5-18b The implants were placed in a single-stage approach using allograft and an ePTFE barrier membrane laterally. (Courtesy of Patrick Wanaka.)

Figs 5-19a to 5-19d Examples of the class C approach.

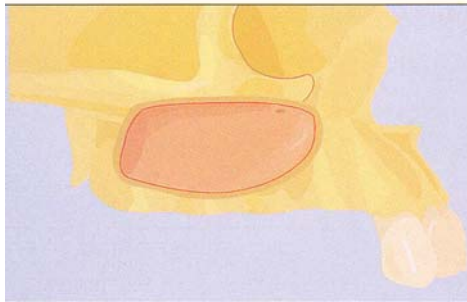


Fig 5-19a

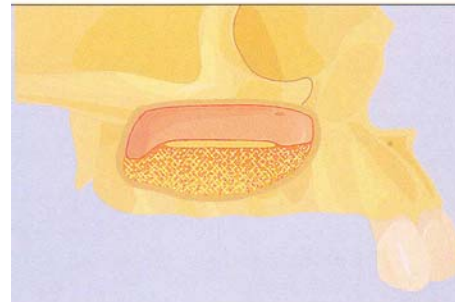


Fig 5-19b



Fig 5-19c

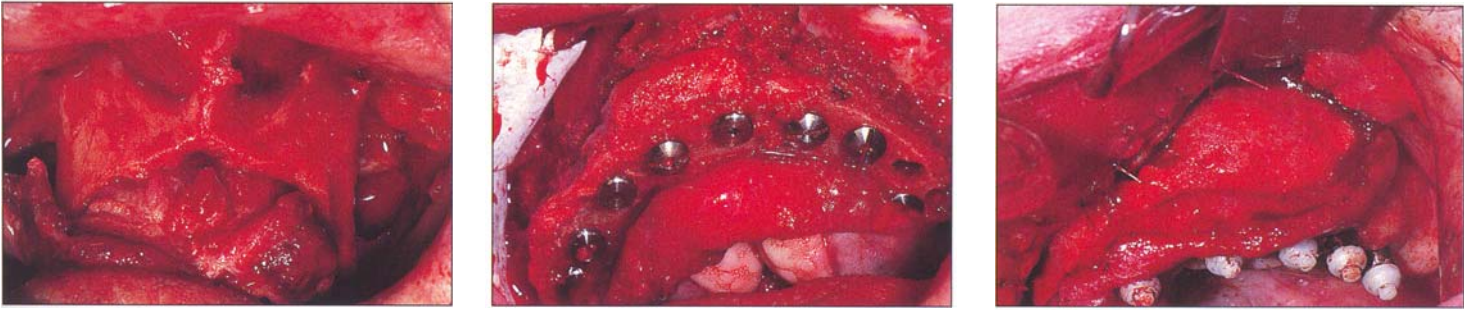


Fig 5-19d

materials, diverse types of implants, and either simultaneous or delayed approaches.³³⁻³⁵ When the simultaneous approach is used, care should be given to maintain the cortical bone during drilling, because it may be the only bone available in the residual basal bone to fixate an implant. Countersinking of this bone could lead to poor fixation of the implant. The osteotome approach has an advantage of maintaining the cortex and compacting the bone, but 6 mm of bone is minimally required to use this approach.³⁶ Lightly countersinking or avoiding countersinking altogether is suggested. Figures 5-19a to 5-19d show examples of the class C approach.

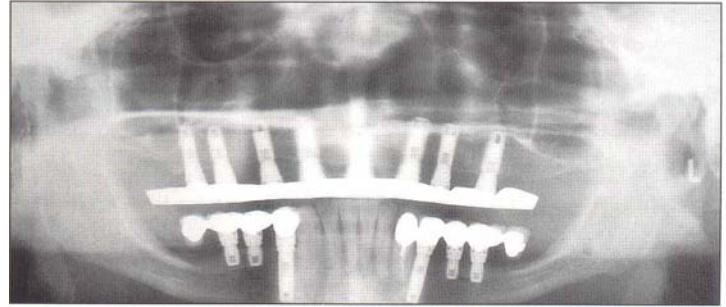
Class D sites

Class D sinus grafting is challenging, particularly if there is no anterior implant placed in several millimeters of native bone to help support (by prosthetic splinting) the distal implants. Highly resorbed maxillae, usually in totally edentulous arches, are particularly difficult to treat with simultaneous implant placement and should be considered for delayed placement 4 to 9 months after grafting. Figures 5-20a to 5-20c show a case in which the sinus grafts were placed in a combined fashion with alveolar augmentation. A 1-year



Figs 5-20a to 5-20c Sinus grafting performed in conjunction with alveolar augmentation. (Courtesy of Dr Ron Yaros.)

Fig 5-20d Ten-year follow-up showing stable bone where implants were placed into the sinus graft in conjunction with alveolar augmentation.



Figs 5-21a to 5-21d Severely resorbed posterior maxilla that has a significant alveolar vertical deficit can be treated with combined alveolar and sinus graft augmentation. A delayed implant approach is used to ensure fixation and stability of the implants for a predictable final splinted restoration.

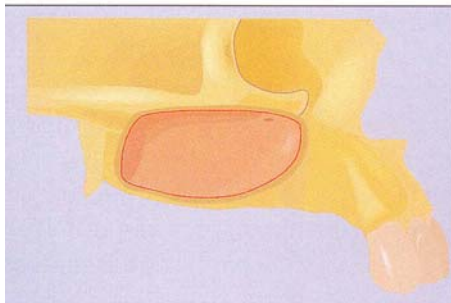


Fig 5-21a

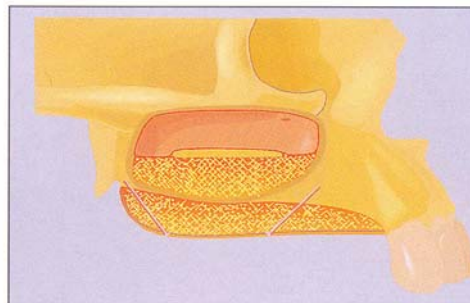


Fig 5-21b

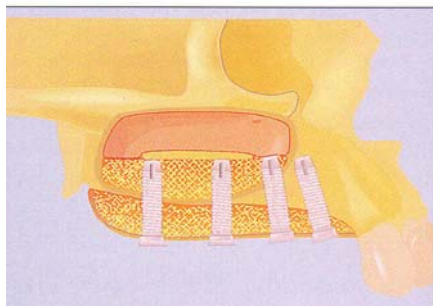


Fig 5-21c



Fig 5-21d

follow-up radiograph (Fig 5-20d) revealed stable bone where conical machined titanium screw-form implants were placed into the sinus graft in conjunction with alveolar augmentation.

A delayed approach (Figs 5-21a to 5-21d), used in recent years, has led to about a 10% higher success rate for implant osseointegration; however, the bone graft

maintenance is not always as good, probably because of the lack of mechanical support of the graft under denture compressive loads during the incorporation period. Table 5-1 shows the increase in bone volume in a group of completely edentulous patients who received class D maxillary sinus grafts in combination with a maxillary alveolar augmentation using iliac bone grafts

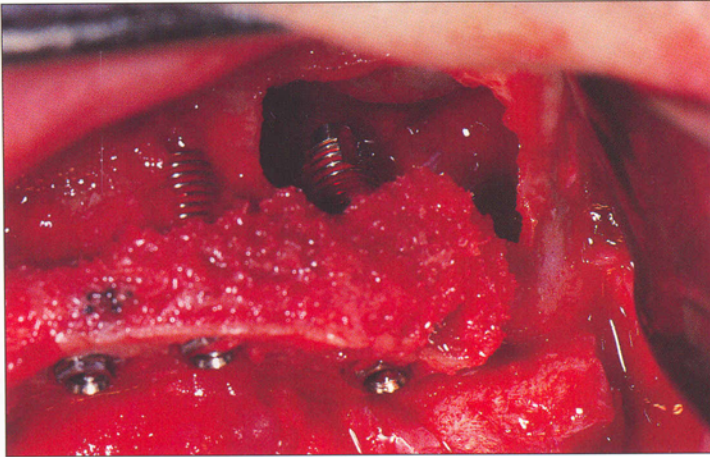


Fig 5-22a Alveolar cortical cancellous block of bone taken from the ilium and secured to the residual alveolus by implants. The implants pass into the sinus cavity under the elevated sinus membrane.

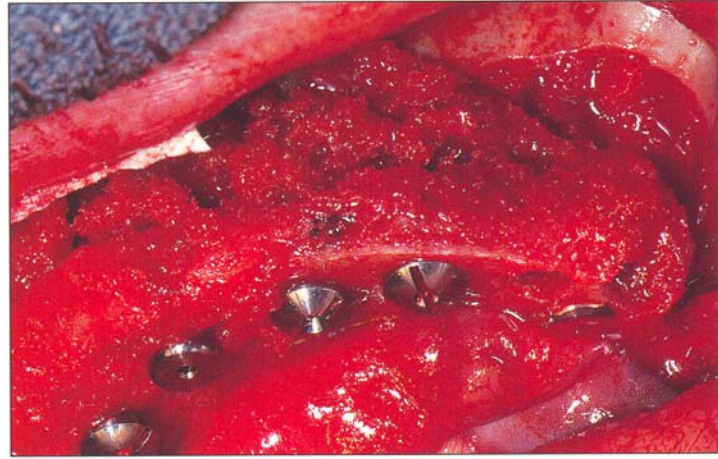


Fig 5-22b Grafted sinus and lateral augmentation to build up the alveolus. (Courtesy of Dr Carl Brownd.)

Table 5-1 Combined maxillary augmentation and sinus grafting with immediate and delayed implant placement in 11 patients

Patient	Year restored	Preoperative average bone volume * (mm)	Bone volume at exposure of implants * (mm)	Net increase (mm)
JHt	1988	2	8	6
SH	1989	2	13	11
DS	1990	3	15	12
LU	1991	1	9	8
ES	1991	1-2	14	12
SA	1991	0-1	15	14
AS	1991	3	14	11
JC	1992	3	15	12
CA	1992	4	15	11
SS	1992	2	13	11
DE	1992	1-2	13	11

* Maxillary bone volume was measured directly at the time of surgery in four positions and then averaged to the nearest millimeter. The measurements are taken at approximately the canine and first molar areas.

At present, these surgeries are reserved for patients with 3 mm or less of residual basal bone.

† No expanded polytetrafluoroethylene barrier was used and no sinus graft was placed.

‡ Seven of eight implants did not integrate. There were no lateral nasal walls, and the sinus cavities were contiguous with the nasal fossa. Despite this, bone volume was increased by a factor of nearly 8 times, and the implants placed at a later date integrated well.

(Figs 5-22a and 5-22b). The 3- to 5-year success rate of implants in this group, now 6 to 10 years postrestoration, was greater than 90% when a delayed approach was used; however, the numbers are still insufficient to draw definitive conclusions about whether a delayed or simultaneous approach is preferable.

Class E sites

The class E sinus grafting case is a category in which the maxilla has been ablated by a gunshot, cancer surgery,

or an anomaly. These cases are extremely difficult to treat. Figures 5-9a to 5-9d show restoration after hemimaxillectomy; the sinus was ablated with a skin graft and the zygomatic arch was then utilized for implant placement.

In Figs 5-10a to 5-10f, ablation of the entire maxilla has left only thin remnants of the zygomatic buttress, the infraorbital wall, and the lateral nasal wall. Implants were placed in available bone simultaneously with guided bone graft augmentation. The maxilla was treated so that a bar-supported obturator-maxillary

denture could function. The patient functioned with this prosthesis for 2 years before succumbing to a recurrence of nasopharyngeal cancer.

Even these rather drastic implant cases, which are not true sinus reconstructive surgeries, but use remnants of the sinus wall, must take into account the direction of the alveolus and the occlusal plane in fixture angulation. Guide stents can be constructed for these complex craniofacial reconstructive cases, which often involve obturators or orbital or midfacial prostheses.

Conclusion

Treatment planning for the sinus graft case must take into account the (1) presurgical osseous bed, which suggests a site classification that dictates the appropriate grafting modality; (2) the alveolar relation, which ensures that implants are sensibly placed and are restorable; and (3) a viable prosthetic treatment plan, that is, the placement of sufficient number, length, and width of implants to satisfy traditional occlusal concepts such as a 1:1 crown-implant ratio, a minimized cantilever moment, and an occlusocentric placement of implants.

When these conservative measures are followed, implants are more likely to osseointegrate, and restorations are more likely to remain in function. Until clinical research has fully elucidated the minimum number, position, length, and width for implants placed in sinus bone graft, these suggested treatment plans, although most certainly overengineered, bear review when the clinician plans to restore the patient successfully to optimal dentoalveolar form and function.

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Use of Allografts for Sinus Grafting

Burton Langer, DMD, MSD Lauren Langer, DDS

The historical development of the sinus elevation procedure originates from the clinical reports of Boyne and James¹ and Tatum,³ who recognized the need to supplement bone inferior to the maxillary sinus to enable clinicians to perform alveolectomies and subsequently place implants. Their efforts led to the development of a technique whereby the external wall of bone surrounding the maxillary sinus was perforated with a careful osteotomy. In Tatum's technique, the osseous wall and underlying membrane were infractured medially and pushed in a superior direction. This required careful dissection of the schneiderian membrane away from the underlying bone, which formed the perimeter of the antrum. The space created by this infracture was filled with an autogenous bone graft. Boyne and James¹ made no attempt to retain this external wall of bone when dissecting the sinus membrane away from the underlying bone.

The sinus cavity is an air filtration space of various dimensions, from approximately 10 to 20 mL in volume. It has the capacity to pneumatize or crenate because of surrounding conditions, such as loss of teeth or chronic irritation, and yet function in relative health. Thus, the reduction in the size of this cavity that results when it is moved superiorly does not pose a serious threat. This, of course, does not include the cases in which the membrane is damaged and bacterial contaminants are introduced into the cavity, resulting in an infection. Overelevating the membrane and thereby occluding the ostium, however, could potentially interfere with the natural drainage and filtration of air and fluids in this cavity.

Although the maxillary sinus is somewhat tenacious in its ability to withstand insults, it must be handled with care to avoid long-standing problems that might seriously affect the patient. Probably the most damaging injury to this structure would be performing the sinus augmentation and losing the surrounding bone, causing an oroantral communication. Although small openings can be closed predictably, large perforations may prove to be resistant to permanent closure. Thus, the clinician should treat this area with respect. Should untoward problems develop during the procedure, it would be wise to abort the surgery and rescue the surrounding anatomy so that it may be treated at a subsequent visit.

Technique

The lateral bony wall of the sinus may be exposed by incising the buccal mucosa, as in the Le Fort I osteotomy, by utilizing a crestal incision, or by employing a design called the overlapped flap.⁴ The Le Fort incision design may give the clearest exposure of the lateral wall of the sinus, enabling the surgeon visibility to elevate it in a superior direction. However, the closure line is directly opposite the window in the bone. Should the sutures pull apart, there is the risk of exposure of the grafted site, which lacks its own blood supply. Consequently, loss of the graft and an oroantral communication would be an undesirable sequela.

Therefore, we customarily employ the overlapped flap as an entry procedure, because this approach allows

maximum tissue coverage over the grafted site. Even if there were tissue sloughing, it would be at a point remote from the grafted area. Second, placement of an intact periosteal covering over the grafted window may have some healing advantages, because many clinicians have reported that the window site is often incompletely healed upon reentry unless they use an occlusive membrane.⁵ This is an uncommon sequela in our experience; we rarely use a membrane for this purpose and routinely obtain complete closure of the buccal wall.

Overlapped flap procedure

A partial-thickness flap is elevated from the palatal side of the edentulous ridge. This split-thickness flap widens at its apical end until it touches the alveolar bone. This design minimizes the amount of vascular embarrassment and sloughing of the coronal edge of the flap, because the base of the flap is wider, preserving an adequate blood supply.

The second step involves placement of two beveled vertical incisions on the outer flap to facilitate flap elevation. If the tuberosity is to be included in the flap, the distal vertical incision may be omitted.

The remaining connective tissue and epithelium covering both sides of the edentulous alveolar ridge are elevated to expose the underlying bone. This double flap can be raised to any desirable position to reveal the necessary anatomic landmarks, such as concavities and sinus prominences. Vertical incisions may be placed to ease the outer buccal flap elevation without any significant compromise in blood supply (Fig 6-1).

After placement of the bone graft, the buccal flap, with its epithelium and connective tissue extension, is coapted over the graft site. If implants or membranes are employed at this same procedure, they will lie under this long covering tissue. Should the buccal or occlusal height be increased intentionally, it may be necessary to lengthen the vertical incisions on the facial side to give the flap additional relaxation and mobility. Additional tissue length can be obtained by incising the undersurface of the flap containing thick connective tissue.

The palatal flap is then coapted over the buccal flap with its extension of connective tissue. This tissue should lie on the surface of the covering connective tissue in a passive manner, completely closing the flap and creating primary intention closure over the surgical site.

Sinus-grafting technique

Once the tissue covering the lateral wall of the maxillary sinus has been elevated, the contour and anatomy of the antrum can usually be identified by its convex appear

ance. Variations in the thickness of the bone on the lateral wall sometimes may mask its perimeter; however, the use of transillumination can be of some assistance.

An osteotomy is performed on the lateral wall of the sinus with a small round bur to the point at which the surgeon can visualize the dark inner lining of sinus membrane (Fig 6-1). Because this membrane is rather fragile, care should be taken to avoid tearing the membrane with the rotary instrument. On the other hand, a bashful osteotomy cut that has not reached the lining membrane will require that the operator use excessive force to infracture the external wall of the sinus cavity. This may also result in a large tear in the sinus membrane, which could compromise the success of the procedure.

Accurate radiographs or tomograms can assist the surgeon to visualize anatomic discrepancies, such as bony septa. It is possible to remove them or to infracture the lateral wall of each compartment that these septa border. The choice is dependent on the amount of bone induction that the surgeon believes the original surrounding osseous structures contribute. The same could be said about the bone that is infractured from the lateral wall of the antrum. It has been reported that the resident bone surrounding a grafted site will provide a good deal of the osteoblasts that will help to form new bone in the augmented area.⁶ Therefore, preservation of native bone will be the preference of most clinicians.

If the outline of the original osteotomy is too small to allow dissection of the membrane from the bone, additional buccal bone may be removed anteroposteriorly and inferiorly to facilitate proper dissection of the tissue away from the bone. Again, all the surrounding walls of bone should be denuded of membrane to allow vascular channels and undifferentiated cells within the osseous structure to help populate the newly forming bone.⁷ This is especially helpful when the material that is employed as a grafting agent is osteoconductive rather than osteoinductive.

We choose to leave at least 3 mm of bone between the inferior border of the trapdoor window and the crest of the ridge. This helps to retain the shape of the original outer wall and gives structure and foundation to support the flap of tissue that will cover the area.

Controversy exists among clinicians as to the amount that it is necessary to elevate the membrane to prepare the site for implant placement. Considering that the average height of the sinus in an adult is approximately 18 to 20 mm, it is not unusual for elevations to vary in degrees of augmentation. The allograft is densely packed into the space created by the elevated membrane (Fig 6-2). The larger the volume of space occupied by a grafting material, the more demanding will be the job of new bone formation; ie, the further from the host bone, the less chance of ossification and more

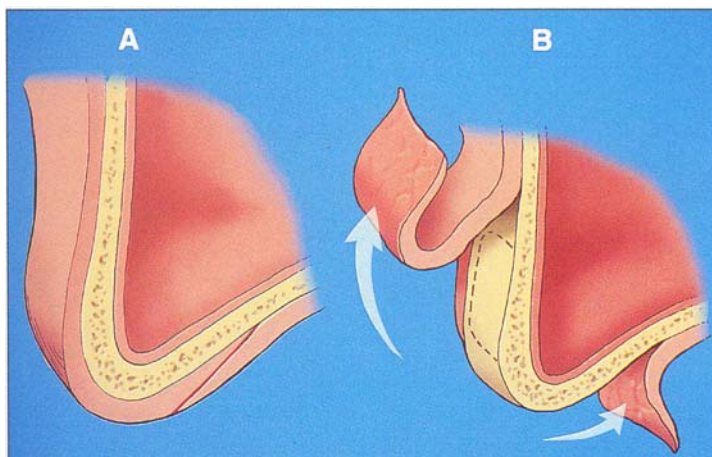


Fig 6.1 (A) A partial-thickness flap is beveled to the palate. (B) The partial-thickness buccal and palatal flaps are elevated, exposing the underlying bone; the osteotomy cut is made in the lateral wall of the sinus.

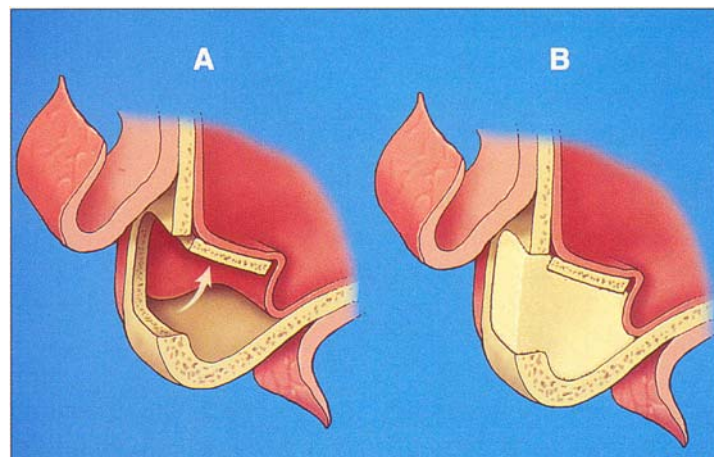


Fig 6-2 (A) The external wall of the sinus is infractured, and the membrane is elevated. (B) The bone allograft is densely packed into the cavity created by the membrane elevation.

chance of graft resorption. The grafted bone will ultimately rely on surrounding vasculature lying within the host bone to revascularize the grafted bone. This is true for all types of graft materials. Thus, in most cases, it is our choice to elevate the bone window-membrane complex approximately 13 to 15 mm, with the expectation that some height will be lost as the graft site slumps during healing.

Graft Material

Although the preponderance of information about sinus grafting has been obtained with autogenous bone grafts,^{1-3,8-11} there has been little in the way of longterm studies on loaded osseointegrated implants in the grafted sinuses. Autogenous hematopoietic marrow grafts are considered the gold standard in grafting materials, because they are osteoinductive. Other materials may be merely osteoconductive and make very little contribution to the bone-forming mechanism.¹² Interestingly, one sinus elevation study using allplastic materials, which have no osteoinductive properties, had a higher success rate than has been reported for autogenous grafts or even implants placed in the most favorable area, the anterior mandible.¹³ Thus, it seems that the area inferior to the maxillary sinus is conducive to new bone growth employing various types of augmentation materials which may have little bone-forming qualities but allow bone to grow around them. Allograft seems to be one such material.

Allografts

The following case reports will discuss our experience with allografts and will be limited to the use of one specific type of allograft, ie, demineralized freeze-dried bone, without any other supplements. The choice of the demineralized material over the mineralized source was merely to add an extra degree of safety to the material. Reportedly, the acidic treatment of the material for the demineralization process adds an extra margin of assurance that viral pathogens will not be transmitted to the patient.¹⁴⁻¹⁸ We do not know that this type of allograft has any more or less osteoinductive capacity than the mineralized source, although it has been reported that bone morphogenic protein is released from the demineralized source.^{19,20} On the contrary, the mineralized variety may offer greater improvement in bone density over the demineralized source in a shorter time frame.

There also may be differences in the bone-forming capabilities of different processing techniques of freeze-dried bone. Some bone banks use different types of sterilization procedures, such as gamma radiation and ethylene oxide, in addition to the normal freeze-drying process; these other processes may enhance or interfere with the bone-forming capacity of the material.^{21,22} What is clear is that the material has been used successfully for bone grafting both in periodontal defects and around implants by many surgeons for reasonable amounts of time.^{18,23-33} It also gives a patient the option to avoid a secondary site from which bone is harvested.

(hip, chin, etc), which may be more traumatic than placement of the implants.

As in all procedures, there are conditions that are not conducive to the use of an allograft for sinus augmentation. The main situation would be in those patients who lack adequate bone in the premaxillary area to support implants under loading (patients who have fewer than 7 mm of bone from canine to canine). While the antral augmentation might be successful, all the forces of occlusion will be generated on the sinusplaced implants, ultimately causing overload and failure. Full onlay and/or inlay autogenous grafts to receive anterior implants would be necessary to dissipate the forces of occlusion.

The second contraindication would be inadequate buccopalatal width of bone in association with the deficiency in height adjacent to the maxillary sinus. This situation would be more conducive to autogenous bone grafts, which could be used as an onlay in combination with particulate matter in the sinus. Finally, patients who have fewer than 4 to 5 mm of bone and wish to have the implants placed at the time of sinus augmentation would best be treated with a large block inlay graft, which could receive the implant simultaneously. Major vertical height advances, which are difficult, are also best treated with autogenous block grafts.

The majority of patients who are seen in the private office environment can be treated with particulate matter allografts. The major consideration would be whether to augment the sinus and wait to place the implants 6 to 8 months later or whether to perform the entire bone graft and implant procedure in one visit. The determining criterion is the amount of residual bone height between the alveolar ridge and the floor of the sinus. If it is fewer than 5 to 6 mm, it would be more prudent to treat the area in a staged fashion, because the success rate will probably be higher and the implant stability will be enhanced with more bone rather than less. This is variable, depending on the density of the patient's residual bone and the bone-forming capability of the patient.

Case Reports

Case 1

A 64-year-old man presented with severe bone loss in the premolar regions. There was insufficient bone to place implants distal to the canines. In addition, the maxillary left second premolar had a periapical infection, which was destroying any remaining bone (Fig 63a). The patient was interested in pursuing an attempt to augment the area of the maxillary sinus without using an accessory site to harvest bone. In 1988, this

was one of the first cases that we had attempted with so little residual bone.

The sinuses were grafted with demineralized freeze-dried bone after the premolars were extracted. The site was allowed to heal for 6 months before the implants were placed. Three implants, ranging from 7 to 15 mm in length, were placed on each side in 1989 (Fig 6-3b). Radiographs confirmed bone stability at the first thread after loading (Fig 6-3c).

Long-cone radiographs were taken in 1993 (Figs 6-3d and 6-3e) and again in 1996 (Figs 6-3f and 6-3g) to evaluate the stability of the bone levels around the implants. No discernible change was noted around any of the implants, including the 10 x 5-mm implant that was placed on the right side at the position of the first molar. We have noticed that the bone quality is commonly weakest in the posterior part of a previously augmented sinus. Thus, we have utilized the wider implants in this area to achieve primary stability.³⁴

It has been possible to maintain a steady state of bone levels around the majority of implants placed in sinus-grafted cases in the same manner as those placed in nongrafted cases.³⁵⁻³⁷ Although it might appear desirable to place only long implants in every case, we have often been surprised at the success of shorter implants, with healthy bone levels prevailing in many of these augmented cases.

Case 2

A 45-year-old woman had three posterior teeth that were considered periodontally hopeless supporting a fixed partial denture (Fig 6-4a). The maxillary sinus was interposed between the first molar and second premolar, making implant placement extremely difficult. Because the patient did not wish to wear a removable appliance, it was decided to extract the second premolar and the second molar and to employ the first molar as a provisional abutment for an interim fixed prosthesis.

At the same visit that the teeth were extracted, the external wall of the sinus was fractured and elevated with the sinus membrane (Figs 6-4b and 6-4c). Both the extraction site and the subantral area were grafted with demineralized freeze-dried bone. After 8 months, radiographs were taken to evaluate the amount of bone growth. It appeared that a significant change had taken place; the area of the invaginated sinus cavity between the molar and premolar was not apparent, and in its place was a segment of bone (Fig 6-4d). At the time of the implant placement, the fractured wall of bone, which was previously filled with particulate allograft, had completely reformed with a dense mineralized repair. The surface of bone was bleeding and was almost indistinct from the original surrounding osseous structure.

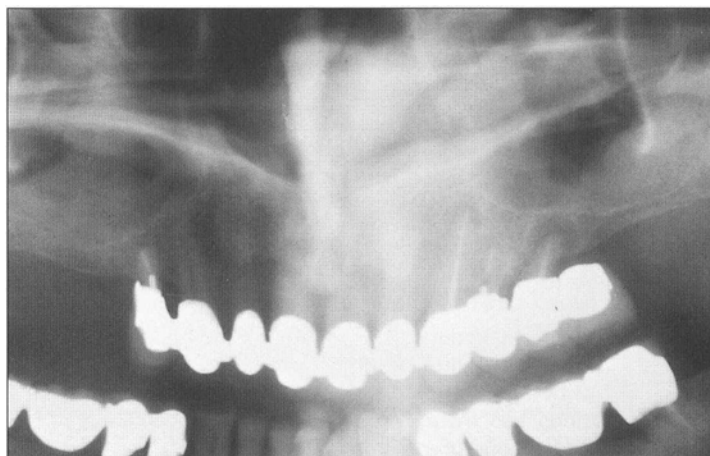
Case 1

Fig 6-3a Panoramic radiograph showing a minimum amount of bone inferior to the maxillary sinus and a periapical radiolucency at the apex of the left second premolar.

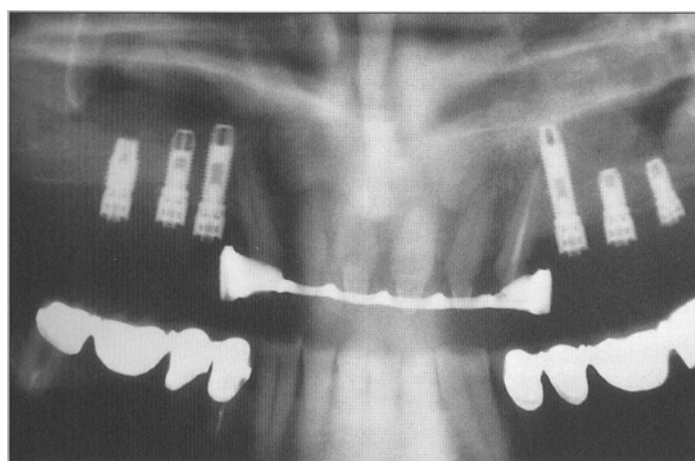
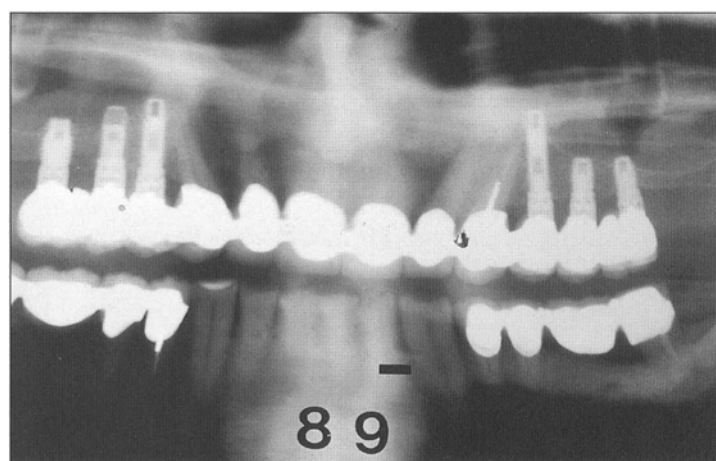
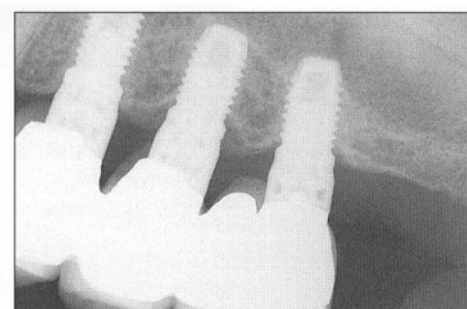
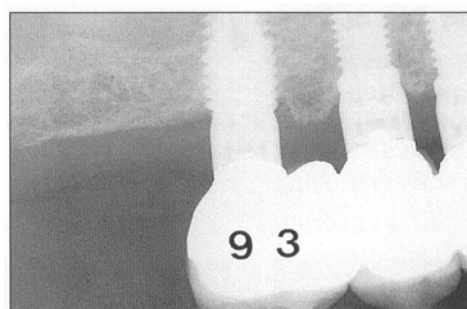


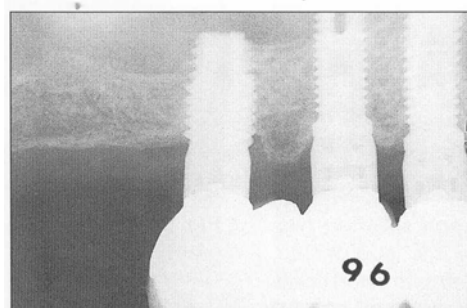
Fig 6-3b Panoramic radiograph, taken in 1989, showing six implants in place after bilateral sinus augmentation with demineralized freeze-dried bone.



Figs 6-3d and 6-3e Four-year postoperative radiographs, showing a steady state of bone at the first thread of the six implants.



Figs 6-3f and 6-3g Seven-year postloading radiographs, showing the same bone level visible in the 4-year radiographs.



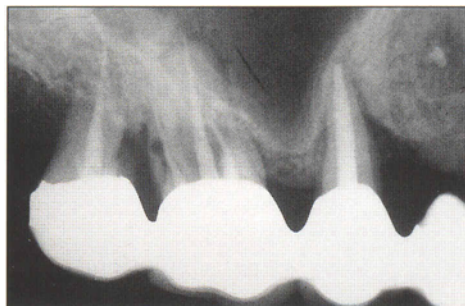
Case 2

Fig 6-4a Periapical radiograph of the maxillary right quadrant. All three teeth are periodontally hopeless, and the maxillary sinus has invaginated between the molar and second premolar.

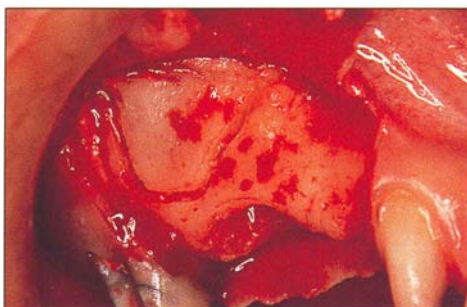


Fig 6-4b An overlapped flap is elevated to expose the buccal bone. The premolar has been extracted, and the osteotomy cut is outlined to prepare the area for a sinus elevation.

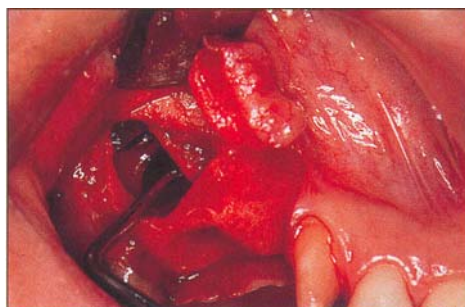


Fig 6-4c The buccal wall is fractured, and the schneiderian membrane is elevated to prepare the area for implants.

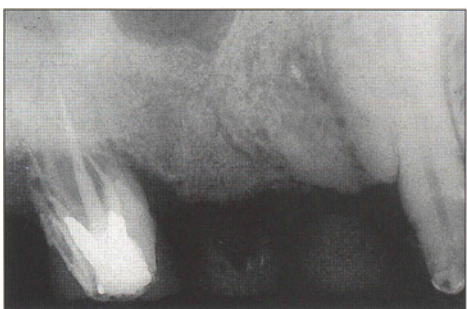


Fig 6-4d Eight-month post-elevation radiograph. There is increased radiopacity in the location of the extracted premolar and an addition of bone in the area previously occupied by the maxillary sinus.

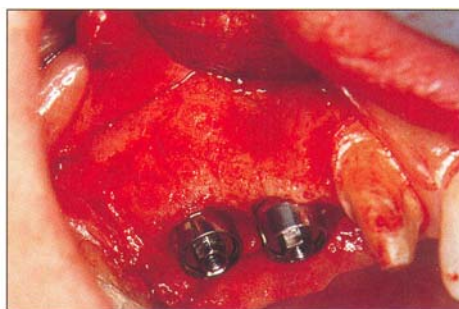


Fig 6-4e At the abutment connection, it was verified that the window of bone that was fractured and grafted has completely filled in with bone.

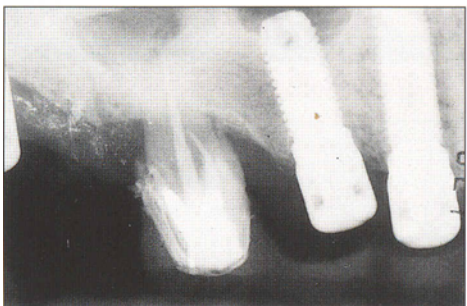


Fig 6-4f Stage 2 radiograph showing two implants in the place of the augmented sinus and extracted premolar and one tuberosity implant.

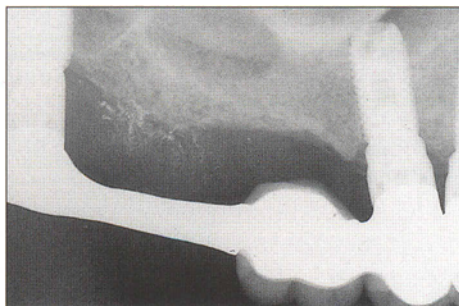


Fig 6-4g Seven-year postloading radiograph.

Case 3

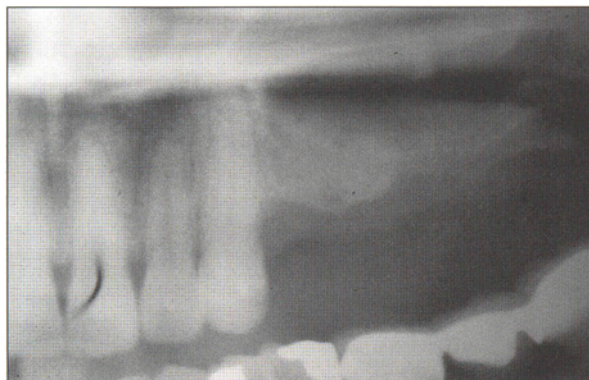


Fig 6-5a Left maxilla. There is 5 mm of bone in the premolar area and 2 mm of bone height in the molar area.

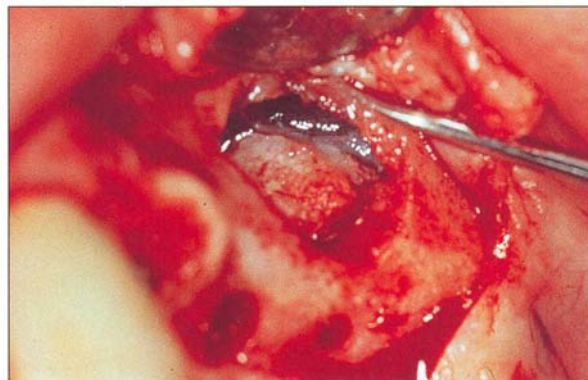


Fig 6-5b Two implants are placed in the premolar area. The technique involved infrafracture of the lateral sinus wall and placement of freeze-dried allograft in the sinus cavity.

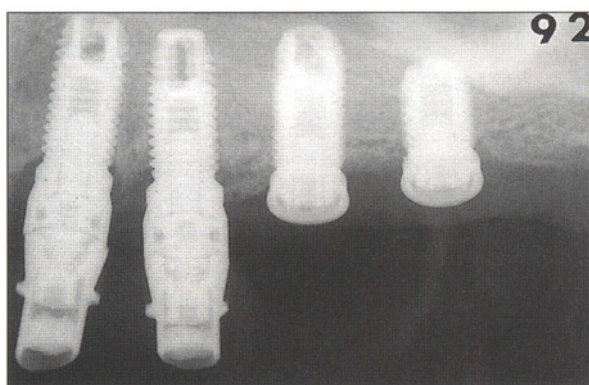


Fig 6-5c At 6 months, the two premolar implants were uncovered and provisionally restored. Two additional implants have been placed in the previously grafted sinus.

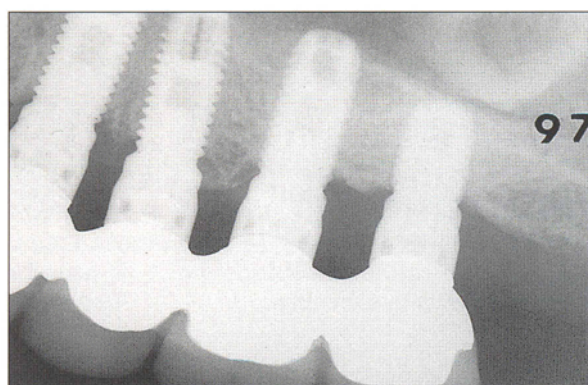


Fig 6-5d Five-year postoperative radiograph of the implants placed in the previously grafted sinus.

Two implants, 10 and 13 mm in length, were placed in the area of the extraction site and the augmented sinus cavity. Both sites had been recipients of allografts. Complete repair of the external wall of the sinus was apparent at the uncovering stage (Fig 6-4e). A third 5mm implant was also placed in the tuberosity to act as a stabilizer for the molar pontic (Fig 6-4f). The implant prosthesis has been functioning in a steady state of health for the past 7 years (Fig 6-4g).

Two 10-mm implants were placed in 1991 and uncovered in 1992 (Fig 6-5c). At the uncovering appointment, two additional implants were placed and allowed to heal for 6 months. The original implants were loaded with an acrylic resin provisional restoration. At the designated time, the remaining implants were uncovered and loaded with a permanent restoration in 1992. Radiographs taken in 1997 revealed that all the implants were maintaining a steady state of health, similar to implants placed in nongrafted sites (Fig 6-5d).

Case 3

Figure 6-5a shows the maxilla of a 34-year-old woman. The available bone immediately distal to the maxillary left canine was approximately 5 to 6 mm in height. In the molar area, the bone height was only 2 mm. Because the patient was anxious to eliminate the removable prosthesis that she was wearing, it was decided to attempt a combination of immediate and delayed implant placement at the time of sinus grafting (Fig 6-5b).

Case 4

In this patient, not only had the maxillary right quadrant lost the molars and second premolar, but also the alveolar ridge had suffered severe bone loss inferior to the maxillary sinus. The external wall of the maxillary sinus was infrafractured from the distal portion of the first premolar to the second molar to receive a bone allograft (Figs 6-6a and 6-6b).

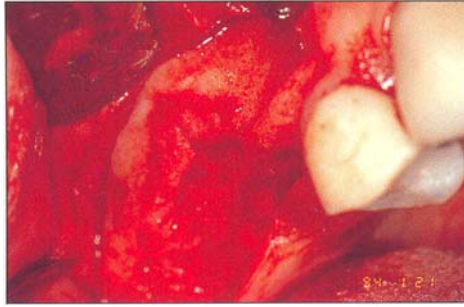
Case 4

Fig 6-6a Severe bone resorption of the maxillary ridge has occurred inferior to the maxillary sinus.

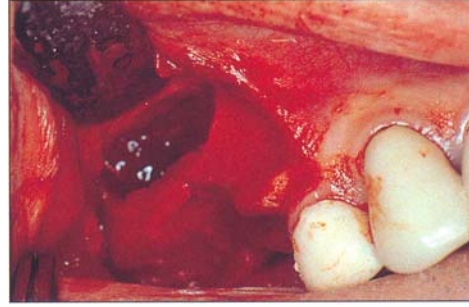


Fig 6-6b The lateral wall of the sinus is fractured, and the trap door and membrane are elevated.

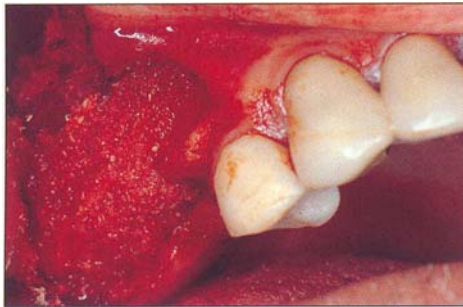


Fig 6-6c Demineralized freeze-dried bone is densely packed into the cavity and the crestal defect to augment the ridge.

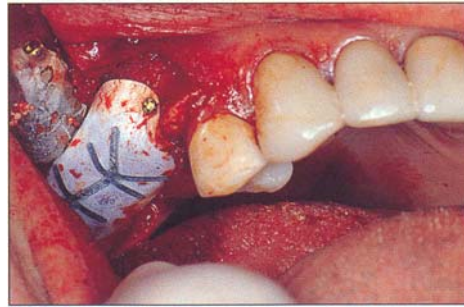


Fig 6-6d A titanium-reinforced membrane is placed to cover the allograft and stabilized by bone screws.

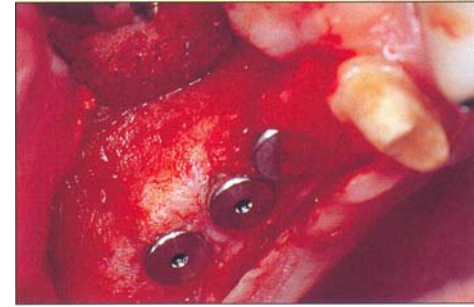


Fig 6-6e Seven months post-elevation, the implants are placed. The buccal bone is completely filled in, and the ridge has been enhanced.

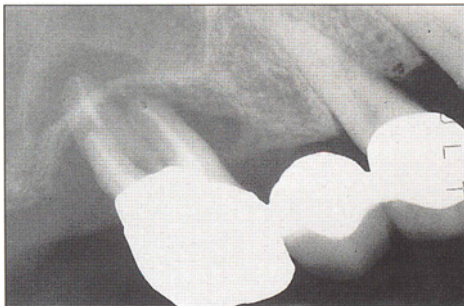


Fig 6-6f Preoperative radiograph. Severe bone resorption of the alveolus is apparent in the molar area. The sinus is at the level of the bone crest.

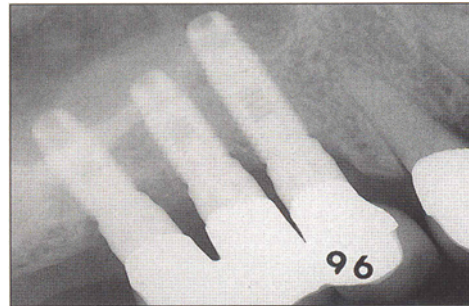


Fig 6-6g Two-year postloading radiograph.

Demineralized freeze-dried bone was packed into the cavity formed by sinus elevation. In addition, the bone allograft was also packed into the residual vertical defect that remained after the teeth were extracted. A titanium-reinforced membrane was placed over the area and stabilized with bone screws. The purpose was mainly to enhance the vertical bone graft inferior to the sinus elevation (Figs 6-6c and 6-6d). The area was closed utilizing the overlapped flap and interrupted sutures. The membrane was removed at the 3-month interval. Implants were placed after 7 months and allowed to integrate for 6 months (Fig 6-6e).

The radiograph taken before the molar was ex-

tracted revealed the severe bone resorption of the alveolus and a highly pneumatized sinus. The 2-year postoperative radiograph showed three implants with well-defined integration in the areas grafted inferiorly and superiorly with a bone allograft (Figs 6-6f and 6-6g).

Case 5

A 59-year-old woman presented as an emergency patient when the maxillary left first and second molars were fractured during prosthesis removal. The radiograph of the maxillary left posterior area revealed a

Case 5

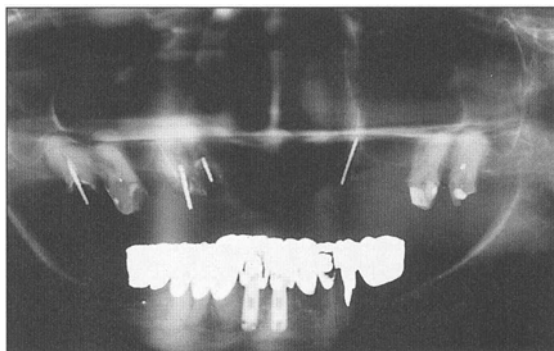


Fig 6- 7a Preoperative panoramic radiograph. There is minimal crestal bone inferior to the sinus.

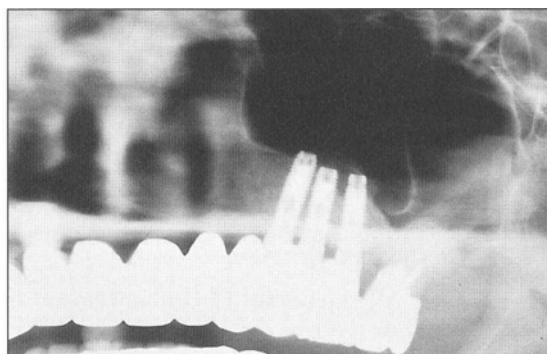


Fig 6-7c Three-year postloading radiograph. One 15-mm and two 13-mm implants were placed.

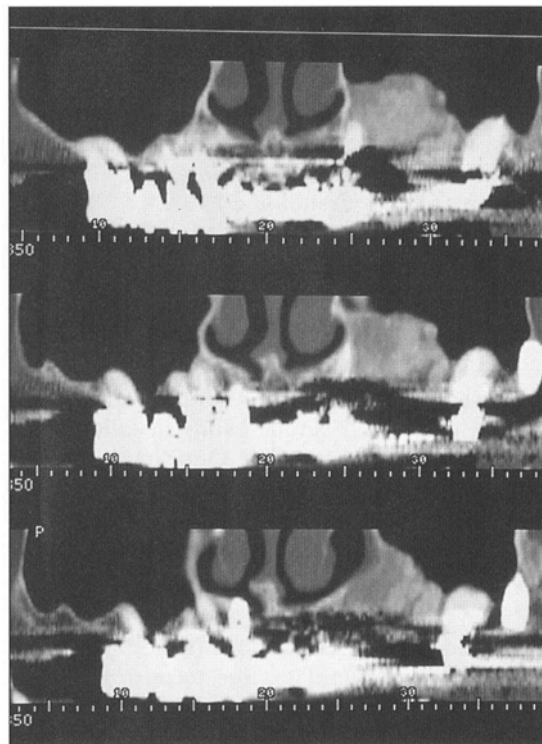


Fig 6- 7b Seven-month postoperative Dentascans to confirm the solidification of the graft.

minimal amount of bone below the maxillary sinus. To allow placement of implants in this area, a sinus elevation procedure was performed (Fig 6-7a).

A Dentascans was taken 7 months after the sinus augmentation and prior to the implant placement. A large amount of radiopaque material was present below the antrum. This was presumed to be new bone that had formed as a result of the sinus graft of demineralized freeze-dried bone. Compare this with the opposite side (Fig 6-7b).

Three osseointegrated implants were successfully placed and loaded in the area of the grafted bone. Starting from a dimension of no more than 1 or 2 mm of bone, we were able to place one 15-mm and two 13mm implants into the grafted area (Fig 6-7c).

Conclusion

We have been performing sinus augmentation since 1988, employing the methodology that has been described. Preliminary retrospective data, gathered by an independent observer from our records of implants placed in grafted sinuses from 1989 to 1994, have indicated a success rate of 82 %. This percentage was based on 107 patients with 188 implants placed in 132 grafted sinuses. They included both delayed and simul

taneously placed implants. Of the 18% that failed, 10% were successfully replaced. Thus, the overall success rate after final loading was 92 %.

The number of cases that have been performed since 1994 has dramatically increased, and the success rate has improved. Cases that previously might have been treated with simultaneous graft and implant placement are now treated in two stages to capitalize on an increased amount of bone to support the implant. Nuances crucial to the overall success of the elevation procedure are now better understood. These factors include incision placement and avoiding the medial portion of the sinus graft when the implant is placed, because it is the least solid portion of the augmented site. This is not always discernible when the implant site is drilled. Finally, the use of wider implants to enhance primary stability in weaker bone has improved results.

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1. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. *J Oral Surg* 1980; 38:613-616.
2. Tatum H. Lectures presented at the Alabama Implants Study Group, 1977.
3. Tatum H Jr. Maxillary and sinus implant reconstructions. *Dent Clin North Am* 1986;30:207-229.

Sinus Grafting with Porous Hydroxyapatite

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The rehabilitation of the partially or completely edentulous maxilla with osseointegrated dental implants has often represented a greater surgical and prosthetic challenge than restoration of the edentulous mandible, in part because of a series of specific anatomic and physiologic differences between the arches. Long-term clinical studies have demonstrated that the bone resorption process that occurs following tooth loss is four times greater in the maxilla than in the mandible.^{1,2} The bone loss encountered in the posterior regions of the edentulous maxillary arch is higher than in the posterior mandible due to the pneumatization of the maxillary sinus. Furthermore, the maxillary cortex is thinner and the trabecular structure is less dense than in the mandible; the posterior maxilla usually exhibits the poorest bone quality. Hence, the quantity and quality of bone necessary for implant-supported restorations are less likely to be available in the maxilla. For these reasons, dental implants placed in the posterior maxilla are likely to have higher failure rates than implants placed in the anterior maxilla or mandible.³⁻⁵

The use of dental implants for the rehabilitation of partially edentulous patients has become a routine treatment concept with a high, long-term predictability.⁶⁻¹⁶ However, a prerequisite for the proper placement of dental implants is an adequate amount of alveolar bone in the recipient area. This is often unavailable in the severely atrophic maxilla.¹⁷ Methods to increase bone volume, such as maxillary sinus augmentation,

onlay bone grafting, and guided bone regeneration, have been described.¹⁸⁻²⁰ However, in partially edentulous patients, the interarch distance is often within normal limits, precluding the use of onlay grafts or guided bone regeneration. Thus, in these instances, the maxillary sinus augmentation procedure represents a treatment alternative.¹⁸ Different bone-grafting materials have been used for this purpose, including autogenous graft from the iliac crest²¹⁻²⁶ and chin region/^{7,28} allografts such as freeze-dried demineralized bone/^{3,29,30} and alloplasts such as porous hydroxyapatite^{24,29-33} and nonporous hydroxyapatite.^{29,32,34}

Although the use of porous hydroxyapatite material in maxillary sinus augmentation appears promising, many scientific questions still remain regarding the biologic response to each of the various bone-grafting materials in the sinus. For example, it is still unanswered whether one type of bone graft is more osteoconductive in the augmented sinus than the others. Furthermore, the histologic nature of the implant-bone interface in the sinus and the response of the augmented area to loading remain unknown.

Thus, in an effort to answer these important questions, our research group has performed a series of experimental, clinical, histologic, and histomorphometric investigations evaluating the use of two porous hydroxyapatite materials and osseointegrated dental implants in conjunction with the maxillary sinus augmentation procedure.

Porous Coralline Hydroxyapatite

One specific area of interest of the sinus consensus conference (Sinus Graft Consensus Conference, Academy of Osseointegration, Wellesley, Massachusetts, November 16 and 17, 1996) was to evaluate the use of a porous coralline hydroxyapatite (Interpore 200, Interpore International) as a sinus augmentation material. Interpore 200 is a coralline hydroxyapatite extracted from the goniopora coral by hydrothermal exchange reaction with phosphate. This material contains trace levels of betatricalcium phosphate.³⁵ The matrix is nonresorbable, and the unique form of the granules mimics the macrostructure of natural bone.

The pores of this matrix material connect one to another to form continuous, uniform channels with no dead ends. The interconnected pores supposedly provide optimal permeability that encourages tissue ingrowth, vascularization, and deposition of new bone.³⁵ Bone healing around this type of bone graft has been characterized initially by fibrovascular invasion into the graft pores, followed by osteoblastic invasion, organization, and lamellar bone apposition on the graft surface.³⁵ The material is commercially available in two granule sizes (425 to 600 μm and 425 to 1,000 μm) and presents a range of pore sizes between 190 and 230 μm .³⁵ It has been evaluated in animals and in humans for a variety of surgical subspecialties, including oral surgery,³⁶⁻³⁹ periodontics,⁴⁰ orthognathic surgery,⁴¹ craniofacial surgery,⁴² and orthopedic surgery.⁴³ In addition, there are some clinical reports of the successful use of this porous hydroxyapatite in the sinus graft procedure.^{29,31}

The physical properties of this porous hydroxyapatite are similar to those of autogenous bone.⁴⁴ However, the ultimate compressive strength is significantly less than that of cortical bone, and the augmentation material has the ability to shatter under peak loads into fragments.⁴⁵ The clinical relevance of this finding is presumably not significant for sinus augmentation procedures. Animal studies have also shown that stress shielding is also not a significant consideration with this bone grafting material and that the newly regenerated bone reacts by a normal remodeling process.^{36,37,41} The functional adaptation of the regenerated bone in zones of stress concentration encourages the use of this bone-grafting material clinically.

The biocompatibility of porous hydroxyapatite was demonstrated by Holmes⁴¹ in mandibular defects in dogs. In six surgically created mandibular defects, 11 %, 46%, and 88% of the implant areas were filled with new bone after 2, 4, and 6 months, respectively. The regenerated bone had the characteristics of immature woven bone up to 2 months; by 6 months it had matured into lamellar. After 12 months, biodegradation of 29% of the porous hydroxyapatite occurred.

Biodegradation began after new bone formation. Finn et al⁶ used porous hydroxyapatite as an interpositional grafting material for the restoration of atrophic mandibular alveolar ridges in dogs. The study demonstrated complete infiltration of the graft pores by immature fibrous connective tissue within 2 weeks. Woven bone and osteoid partially filled the implant channels at 3 months. Initial deposition of osteoid and woven bone formation was followed by remodeling into a lamellar bone-type pattern. Piecuch³⁹ also demonstrated infiltration of the porous hydroxyapatite granules by connective tissue and bone in human biopsy specimens.

Similar histologic observations were found in an experimental study by our research group.⁴⁶ The aim of the study was to evaluate, clinically and histologically, the application of porous coralline hydroxyapatite (Interpore 200) as a bone-grafting material for maxillary sinus augmentation procedures. The effect of simultaneous and delayed dental implant placement and the influence of loading on the augmented area and implant-tissue interface were also evaluated in this study. Histologic analysis demonstrated a significant amount of new bone formation in the augmented sinuses. The Interpore 200 granules were embedded in newly regenerated bone and immature connective tissue in all three areas (medial, apical, and lateral) of the augmented sinuses. The lateral area of the loaded group exhibited an average of 27.7% new bone, 31.9% connective tissue and fatty marrow, and 40.4% graft granules. The percentage of new bone in all regions was similar. The percentage of direct contact between new bone and implant surface in the augmented area was greater in the delayed implant groups than in the simultaneous placement group. Also, loading of the implants enhanced bone apposition to the implant surface. It was concluded that the porous coralline hydroxyapatite bone graft enhances bone formation and bone-to-implant contact in the augmented sinuses.

The slight lymphocytic inflammatory response around porous hydroxyapatite graft particles was reported in a study where human biopsy specimens were obtained from sinuses augmented with Interpore 200 material.⁴⁷ Smiler and Holmes⁴⁸ augmented the maxillary sinus of four patients with porous hydroxyapatite and histomorphometrically evaluated the biopsy specimens from those areas after 4 to 5 months of healing. The authors reported an average of 23 % new bone, 45 % connective tissue, and 32 % porous hydroxyapatite granules. These values were confirmed by Moy et al.³¹ The specimen of one patient revealed attainment of 20% new bone, 47% connective tissue, and 33% graft particles.

In a clinical study, 203 hydroxyapatite-coated cylinder implants (IMZ) were placed in sinuses that were

augmented with porous hydroxyapatite alone.²⁴ During an average observation time of 17 months, only 13 implants (6.4%) failed. In this short-term trial, the authors concluded that this bone graft is effective for sinus augmentation.

Porous Bovine-Derived Hydroxyapatite

Bio-Oss (Geistlich) is a particular inorganic bovine bone matrix of calcium-deficient carbonate apatite with a crystal size of approximately 10 nm.^{49,50} The material is commercially available in three particle sizes (250 to 1,000 nm, 500 to 1,000 nm, and 1,000 to 2,000 nm) as well as in two different bone types (cortical or cancellous bone). The osteoconductive xenograft has slow degradation kinetics because of the applied manufacturing technology and the chemical structure. All proteins are removed during various chemical and physical processes, which are performed under Good Manufacturing Practice (GMP) and International Standards Organization (ISO) 62001 guidelines. The surface area of each graft particle is considerably greater than that of porous synthetic bioceramics, and the modulus of elasticity is similar to that of natural bone.^{49,51}

Previous studies in animals^{49,52-57} and in humans^{29,58-63} have evaluated this bone graft both clinically and histologically in a variety of applications, obtaining promising results. The biocompatibility of this bone graft was demonstrated by Denissen et al⁶⁴ and Paul et al.⁴⁹ Paul et al.⁴⁹ found no foreign-body reaction to the bone graft in the rabbit tibia over 1-, 6-, and 12-month periods of healing. Osteoclasts were identified in lacunae, suggesting a physiologic bone remodeling around the graft particles and newly formed bone. In another investigation in the rabbit, Schlickeewei and Pau¹⁵⁴ demonstrated that this bone graft appeared to enhance bone healing in standardized defects in the rabbit tibia or femur in comparison to control defects. The authors stated that the bone graft appeared to have acted as a scaffold for new bone formation.

Boyne⁵³ augmented the sinuses of five *Macaca fascicularis* monkeys with a mixture of one third autogenous bone, one third demineralized freeze-dried bone, and one third Bio-Oss while simultaneously inserting two endosseous oral implants. The histomorphometric analysis of the area around the implants after 14 months of loading identified an average of 16.3% new bone in the augmented area. The average percentage of new bone regeneration in an experimental as well as clinical study of our group was much higher (27.4%). The reason for this discrepancy could be the fact that Boyne⁵³

used demineralized freeze-dried bone from humans in the monkey. It may be that the demineralized freeze-dried bone had a negative effect on bone healing in this model.

Jensen and Greer²³ also demonstrated negative results when they used demineralized freeze-dried bone in the sinus augmentation procedure. Of a total of 60 self-tapping Branemark implants (Nobel Biocare) placed simultaneously with the sinus graft procedure, 19 (32 %) were lost during an observation period of 2.5 years. Smiler et al⁹ also published the results of 15 sinus grafts with the use of demineralized freeze-dried bone. They concluded that this material alone is not able to create a load-bearing implant bed and that the material should be mixed with another bone substitute.

The question of whether to place the endosseous implants simultaneously with the sinus graft or in a delayed approach following the augmentation has been evaluated in a number of experimental and clinical studies. Khoury et al⁶⁵ recommended simultaneous insertion, whereas Jensen and Greer²³ and Jensen¹⁷ preferred delayed implant placement. The determining factor appears to be ensuring primary stability of the implants. According to Jensen and Greer²³ if the primary stability can be obtained in the residual bone, then simultaneous implant placement is possible. Furthermore, these authors suggested that at least 4 to 5 mm residual bone height is necessary to guarantee primary stability of the implants for the simultaneous procedure. The advantage of the simultaneous procedure is the shorter period of healing and the elimination of one surgical procedure. In terms of clinical success rate, however, the available data so far favor delayed implant placement. Jensen¹⁷ reported a success rate of 81 % with simultaneous placement and 93% with the two-stage procedure. In an experimental study by Hürzeler et al,⁶⁶⁻⁶⁸ delayed implant placement resulted in a significantly higher percentage of direct mineralized bone-to-implant contact in the augmented area on both the unloaded and loaded sides. However, the timing of endosseous implant placement did not demonstrate an influence on the peri-implant bone loss.

In addition, the findings from one study suggest that loading has a possible positive effect on the amount of direct mineralized bone-to-implant contact.⁴⁶ Although a difference in healing time existed between the loaded and unloaded groups, in terms of new bone in the three areas around the implants there was basically no difference between the loaded and unloaded implants. However, when the percentages of direct mineralized bone-to-implant contact were compared, the loaded implants exhibited much higher values than did the unloaded implants. These findings occurred not only in the residual bone but also in the augmented new bone.

A previous histologic investigation demonstrated that immature, woven bone forms first around a dental implant following its placement.⁶⁹ This woven bone is subsequently replaced by lamellar bone during the normal healing and remodeling processes.⁷⁰ In our experimental study, abrasion facets were detected on the occlusal surfaces of the implant-retained suprastructures following loading. Histologic analyses of the implant-augmented bone interface demonstrated the presence of mostly mature lamellar bone in close contact with the implant surface.

It is well known that loading of endosseous oral implants results in greater mineralization of the surrounding bone.^{69,71,72} Kohri et al⁷² demonstrated that bone apposition was greater on loaded implants compared to the unloaded implants. Takuma et al⁷³ also found a thickening of the trabeculae in the peri-implant bone of loaded implants in the mandible of beagle dogs. The similarities of the results in these investigations and our studies suggest that the implant bed reacts according to Wolff's law⁷⁴ on loading by an increased mineralized bone-to-implant contact.

Clinical Evaluation

Method and materials

Patient selection

Between September 1, 1988, and July 31, 1997, 798 sinus grafts were performed using three different porous hydroxyapatite materials with or without autogenous bone grafts. The patient group, from a private practice in Stuttgart-Filderstadt, Germany, comprised 552 patients (Fig 7-1); 336 (60.9%) were women and 216 (39.1 %) were men. The mean age of the patients at the time of surgery was 54 years. Patients were not accepted for endosseous implant surgery if they did not fulfill the general requirements for surgery.

Preoperative and postoperative patient medication

One day prior to surgery, the patients were instructed to begin taking amoxicillin, 250 mg, four times per day, and ibuprofen, 400 mg, three times per day, and also to begin rinsing with chlorhexidine gluconate, 0.12%, three times per day. This medication regimen was continued until 7 to 10 days postsurgically.

Surgical therapy

The sinus grafts were carried out by a modification of the technique described by Boyne and James¹⁸ (Figs 7-2 and 7-3). Briefly, a supracrestal incision and two long

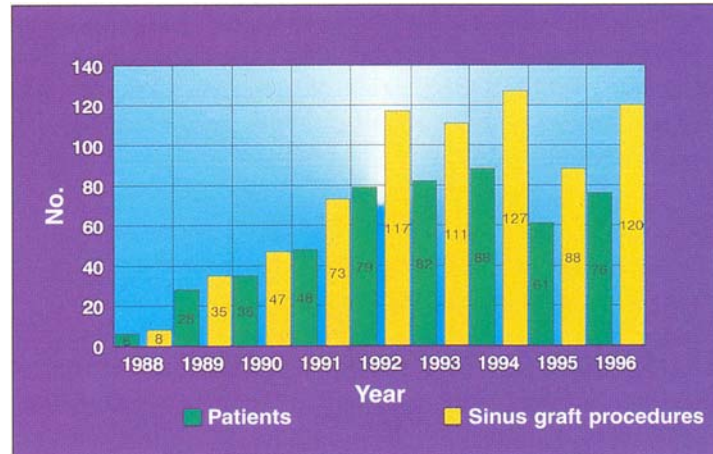


Fig 7 -1 Distribution of sinus graft procedures from September 1988 through July 31, 1997.

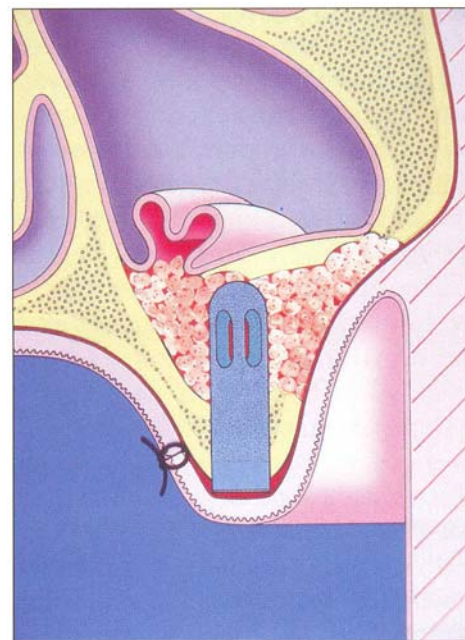


Fig 7-2 Sinus graft with porous hydroxyapatite as the grafting material.

vertical incisions extending beyond the mucogingival junction were made, and a full-thickness flap was reflected to gain access to the underlying alveolar bone. An oval-shaped osteotomy was then prepared with rotary instruments used under copious sterile saline irrigation. A round diamond-coated bur 4 mm in diameter was used to prepare the outline of the osteotomy window. The rationale for using a large bur is to control the thinning of the cortex without rupturing the schneiderian membrane. Specially designed elevators were then used to carefully elevate the sinus membrane. After the necessary membrane elevation was obtained, the implant beds were drilled following the IMZ surgical protocol,⁷⁵

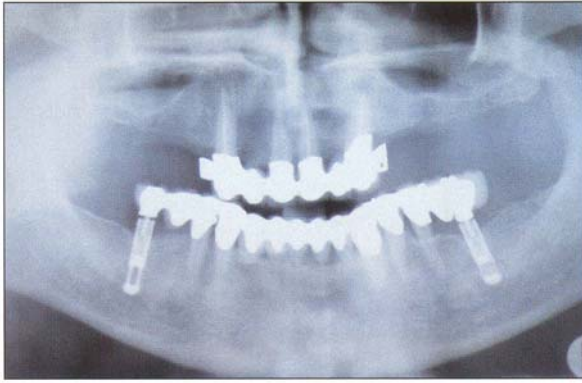


Fig 7-3a Panoramic radiograph of a 54-year-old patient.

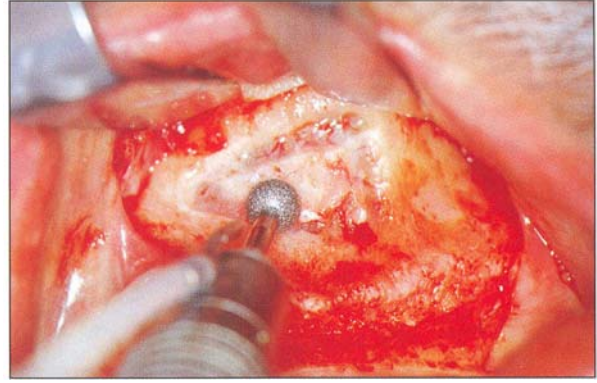
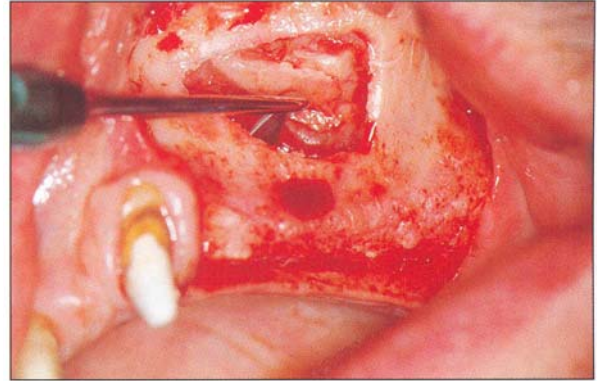
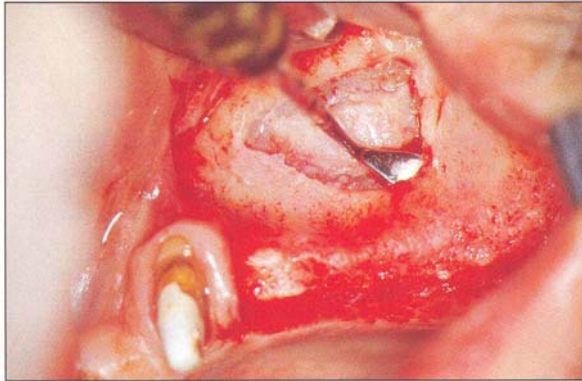


Fig 7-3b An oval-shaped osteotomy can be prepared with rotary instruments used under copious sterile saline irrigation. Hence, the implant recipient sites can be anticipated while the intra sinus penetration can be directly visualized and controlled.



Figs 7-3c and 7-3d Specially designed elevators are used to carefully elevate the sinus membrane.

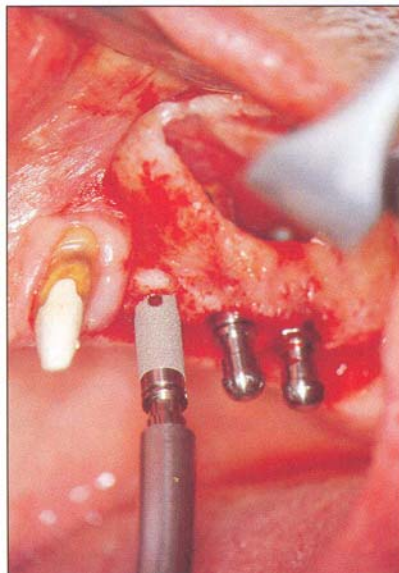


Fig 7 -3e After the necessary membrane elevation is obtained, the implant beds are drilled according to the IMZ surgical protocol. Then the grafting material is placed and condensed into the depth of the sinus cavity. Titanium plasma-sprayed cylinder implants, made of pure titanium, are placed in a location that will facilitate the fabrication of an esthetic, functional, and hygienic restoration.



Fig 7 -3f After implant placement, additional bonegrafting material is applied until the entire volume of the sinus window is filled.

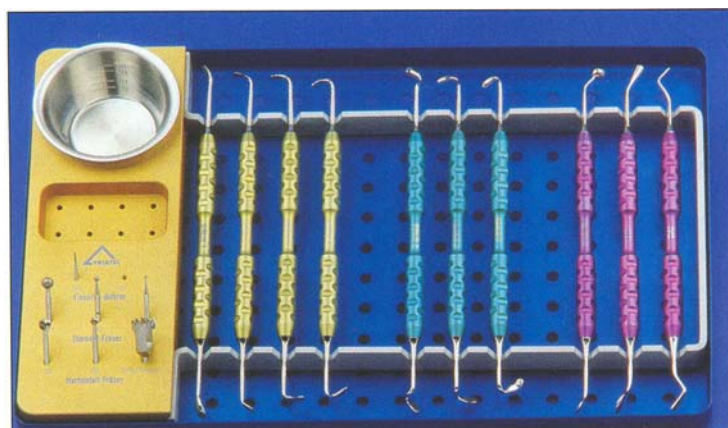


Fig 7-3g FRIOS sinus set (Friatec).



Fig 7-3h Clinical appearance 4 years after completion of the implant prosthetic treatment.

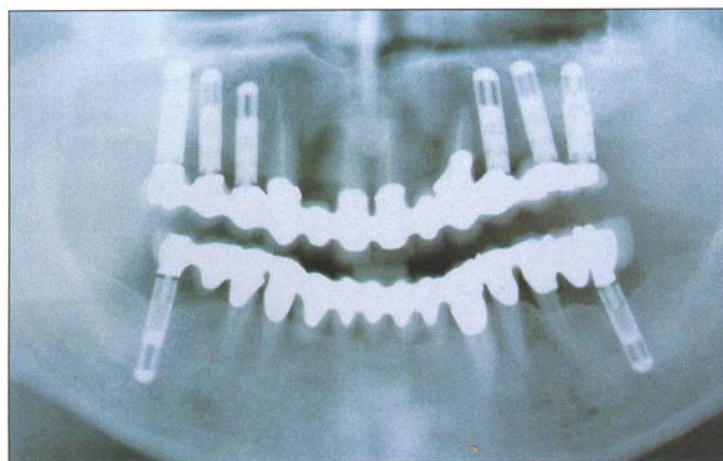


Fig 7-3i Panoramic radiograph of the implant-supported restoration (definitive ceramometal fixed prostheses) in the mandible and maxilla, 4 years postoperatively.

Table 7 -1 Distribution of grafting materials used in sinus grafts from September 1988 through July 31, 1997

Graft material	No.
Interpore 200	82
Bio-Oss	393
Interpore 200/Bio-Oss	135
Algipore	24
Interpore 200/autogenous bone	112
Bio-Oss/autogenous bone	60
Algipore/autogenous bone	27
Without grafting material	5

One of eight different grafting material combinations was placed and condensed into the depth of the sinus cavity (Table 7-1). Endosseous oral implants (IMZ twin plus) made of pure titanium were placed in a location that would facilitate the construction of an esthetic, functional, and hygienic restoration. After implant placement, additional bone-grafting material was applied until the entire volume of the sinus window was filled. Soft tissue closure was achieved without creating undesirable tension on the flaps.

Bio-Oss was used in 358, Interpore 200 in 82, and Algipore (Friatec AG) in 20 sinus grafts (Table 7-1). In 135 cases, a mixture of the porous coralline hydroxyapatite (Interpore 200) and the porous bovine-derived hydroxyapatite (Bio-Oss), in a 1:1 ratio, was employed as augmentation material. All three bone substitutes were also mixed with particularized autogenous bone grafts (Interpore 200/autogenous bone in 112, Bioass/autogenous bone in 55, and Algipore/autogenous bone in 25 procedures). In 27 maxillary sinus augmentation procedures, monocortical bone blocks were applied.

Autogenous bone was obtained from the iliac crest for 70 Interpore procedures, 22 Bio-Oss procedures, and 23 Algipore procedures; bone was harvested from the retromolar and chin regions for 42 Interpore grafts, 33 Bio-Oss grafts, and 2 Algipore grafts. One hundred fifty sinus floor augmentation procedures in 184 patients were combined with a guided bone regeneration treatment concept. From 1988 to 1994, expanded poly tetra-fluoroethylene membranes (Gore) and titanium minitacks (Steri ass) were used, and from 1994 to July 1997, bilayered collagen membranes (BioGide, Geistlich) and bioresorbable minitacks (ResorPin, Geistlich) were used. Four patients were treated without any augmentation material. The sinus grafting involved 641 one-stage procedures, 125 two-stage procedures, and 32 combination one-stage and two-stage procedures. Of the 157 (125 two-stage and 32 combined) procedures, 93 allowed a histologic evaluation (Figs 7-4 to 7-6).

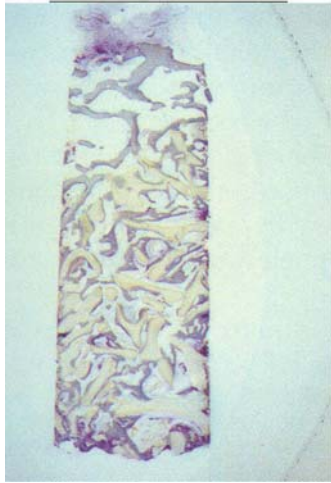


Fig 7-4a Photomicrograph of a gross specimen from region 17, obtained from trephine drill biopsy, 6 months postoperatively. The grafting with deproteinized natural bovine cancellous bone resulted in new bone formation and bone apposition to the Bio-Oss granules. (Original magnification x 8; toluidine blue stain.)

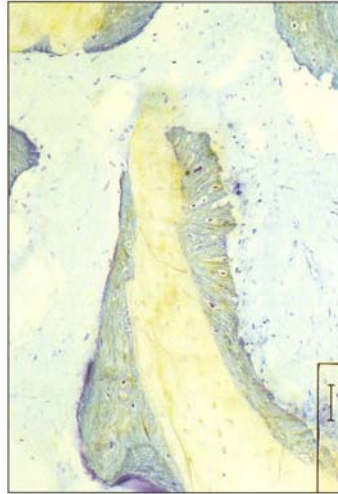


Fig 7-4b High-magnification photomicrograph from a specimen treated with a sinus graft in combination with porous bovine hydroxyapatite. New bone formation is present around a pure inorganic hydroxyapatite particle without fibrous encapsulation. (Original magnification x 40; toluidine blue stain.)

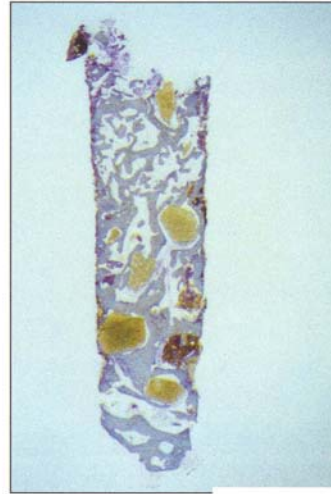


Fig 7-5a Photomicrograph of a gross specimen, obtained from trephine drill biopsy, 9 months postoperatively. A moderate amount of woven bone surrounds the granules of Interpore 200. (Original magnification x 8; toluidine blue stain.)



Fig 7-5b High-magnification photomicrograph from a specimen treated with a sinus graft in combination with porous coralline hydroxyapatite. New bone formation is present around a hydroxyapatite particle without fibrous encapsulation. (Original magnification x 25; toluidine blue stain.)

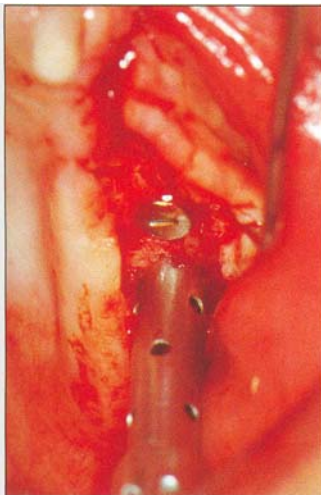


Fig 7-6a A 3-mm-diameter trephine drill is used to drill the graft site to prepare a core graft material at least 10 mm in length. This technique allowed a histologic view of the osseous graft-soft tissue interface and osseous graft-implant interface with minimal distortion.



Fig 7-6b Specimen obtained for histologic evaluation.

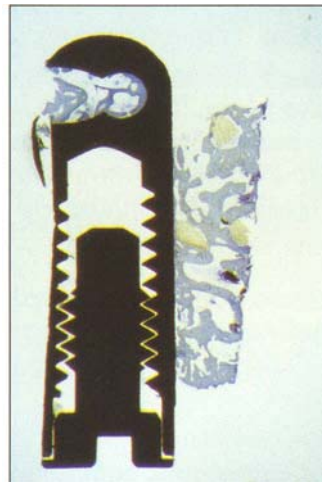


Fig 7-6c Photomicrograph of a gross specimen, obtained from the trephine drill biopsy, 9 months postoperatively. A moderate amount of woven bone surrounds the granules of Interpore 200. Sufficient mineralized bone-to-implant contact is present in the augmented area. (Original magnification x 8; toluidine blue stain.)



Fig 7-6d High-magnification photomicrograph from a specimen treated with a sinus graft in combination with porous coralline hydroxyapatite. New bone formation is present at the cylinder implant-bone interface and around the hydroxyapatite particles without fibrous encapsulation. (Original magnification x 25; toluidine blue stain.)

Implants were immediately placed into the sinus when approximately 4 mm of crestal bone was present and if primary stabilization was obtained. Where less than 4 mm of bone was present or where no primary implant stabilization was obtained, implant placement was delayed until 6 months after the augmentation procedure (Figs 7-7a to 7-7c). A total of 1,538 pure titanium, plasma-sprayed cylinder implants (IMZ) with a diameter of 4 mm and different lengths were employed in this study. A total of 1,311 implants were placed at the same time as the sinus augmentation procedure, while a total of 227 implants were placed 6 months after augmentation. A mean of 2.8 ± 1.7 implants

(range: 1 to 8) were placed per patient. All implants were placed under sterile conditions, following a standard protocol that has been described elsewhere.⁷⁵

Prosthetic phase

The implants were allowed an osseointegration phase of 6 months prior to initiation of the restorative phase. At this time, the implants were surgically exposed, and the transmucosal implant extensions and healing caps were connected. All implants utilized an intramobile element composed of a polyoxymethylene, a medical-grade polymer. This resilient insert allowed the fabrication of clinically predictable, mechanical and biomechanical, screw-retained connections between implants and teeth. All prostheses were constructed and placed following the standard restorative principles of the IMZ system.⁵ All superstructures were metal veneered with porcelain and were fixed-detachable (Figs 7-8a and 7-8b). The types of superstructure were classified as follows, depending on the kind of abutments used:

- . Type I: Implants in the augmented sinus combined with implants placed mesial to augmented sinus
- . Type II: Implants in the augmented sinus combined with natural teeth . Type III: Implants in the augmented sinus alone . Type IV: Implants in the augmented sinus combined with natural teeth and other implants placed mesial to the augmented sinus

Clinical parameters

A series of clinical and radiographic parameters were measured at selected intervals through the observation period. All prostheses were removed every 12 months, and the following clinical parameters were measured for each implant inserted in the augmented sinus:

1. *Implant mobility*: Orofacial implant mobility was clinically determined with the metal handles of two dental instruments, such as mirrors, which were used to subject the implant to a rocking force.
2. *Clinical attachment level*: The distance from the top of the implant abutment to the bottom of the clinical sulcus was measured with a calibrated periodontal probe (HH 12, Deppeler) on the midbuccal aspect of each implant.
3. *Gingival index*: The peri-implant gingival tissue was assessed on the midbuccal aspect of each implant using a simplified gingival index proposed by Aspe et al.⁶

Radiographic parameters

Panoramic radiographs were taken prior to the sinus augmentation surgery, at abutment connection, at completion of the restoration, and, thereafter, at yearly intervals.

Complications

The types and occurrence of complications are listed in Table 7-2. No postoperative wound dehiscence was detected because of appropriate soft tissue management and highly reliable patient compliance. In 30 cases (3.2 %) the surgical procedure was terminated because of major rupture of the schneiderian membrane. Minor membrane rupture occurred in 57 (7.3%) of the procedures; however, surgery could be continued. An infection was found in 21 patients (3.4%), resulting in the loss of 12 implants and 6 augmentation sites.

Table 7-2 Complications arising from sinus grafting (September 1988 through July 31, 1997)

Wound dehiscence	0
Major membrane rupture*	30
Minor membrane rupture	64
Infection	23
Loss of implant	12 [†]
Loss of augmentation	6 [‡]

* Surgical procedure discontinued.

† Nine early, three late.

‡ One total, five partial.

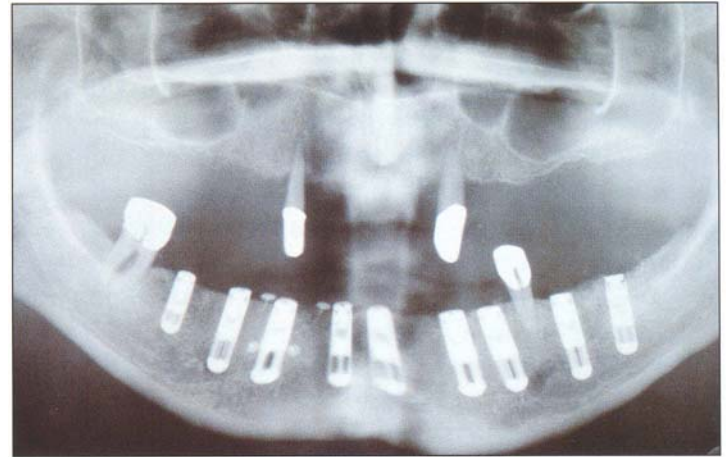


Fig 7- 7a Panoramic radiograph of a 49-year-old patient. The atrophic posterior maxilla presented with less than 4 to 5 mm vertical residual bone height. Hence, delayed implant placement is required.

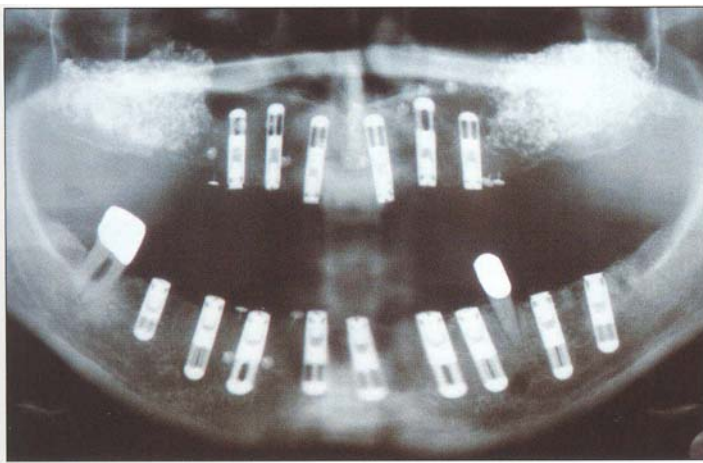


Fig 7 - 7b Panoramic radiograph taken 9 months after the two-stage sinus grafting with Interpore 200 on both sides and placement of seven 4-mm-diameter titanium plasma-sprayed cylinder implants in the alveolar bone.

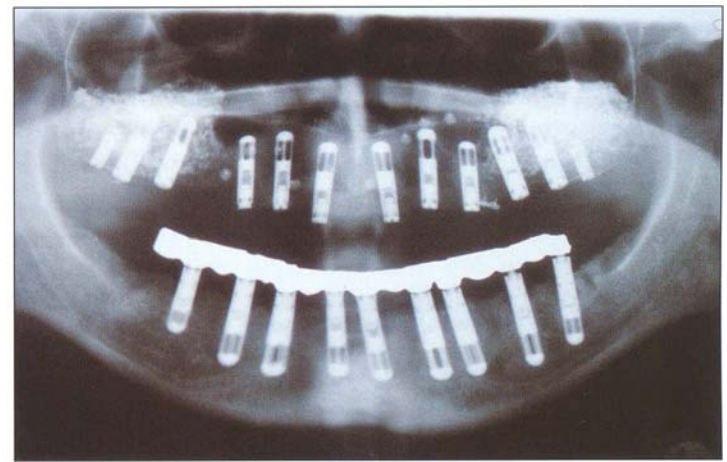


Fig 7-7c Panoramic radiograph taken 9 months after the placement of four 4-mm-diameter titanium plasma-sprayed cylinder implants, two on each side, in the augmented sinus. In addition, two 8-mm-diameter titanium plasma-sprayed cylinder implants were placed in the posterior graft for histologic evaluation.



Fig 7 -8a Clinical appearance 3 years after the implant prosthetic treatment was finished.

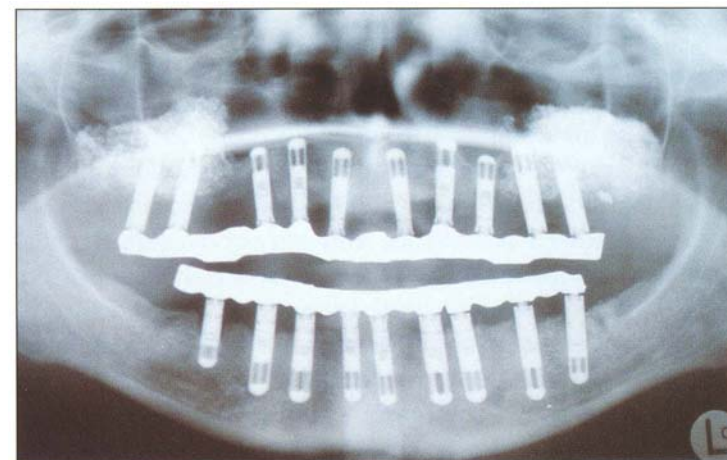


Fig 7-8b Panoramic radiograph of the implant-supported restorations 3 years postoperatively.

Results

Nine of the implants placed in the augmented sinuses failed prior to placement of prostheses (99.4% of all implants primarily achieved osseointegration), and only three (0.2 %) failed to maintain osseointegration afterward, yielding an implant survival rate of 99.1 % over the entire course of the evaluation period. Between September 1, 1988, and July 31, 1997, 1,174 implants were restored with a total of 339 fixed-detachable ceramometal prostheses; the longest follow-up was 95 months.

The patient's gender, the implant length or localization, the remaining bone height, and the type of bone augmentation material had no effect on implant success. None of the 339 fixed ceramometal prostheses was lost during the observation period. The results of this study support the long-term clinical predictability of maxillary sinus augmentation procedures with porous hydroxyapatite for the rehabilitation of the edentulous posterior maxilla with implant-supported prostheses.

Hydroxyapatite-Coated Dental Implants with Porous Hydroxyapatite

The use of hydroxyapatite-coated dental implants has been recommended in type IV bone.^{77,n} Histomorphometric analyses of core biopsy specimens from augmented sinuses revealed them to be, in most cases, quality IV.^{31,47,48} Therefore, the "ideal" properties of crystalline hydroxyapatite implant coatings may represent an edge over titanium implants placed in this particular location. The results seem to indicate that the hydroxyapatite coating of the implants acted as an osteoconductive scaffold, facilitating bone formation around the implant periphery and into the augmented sinus. A similar observation was noted by Zablotzky et al⁹ and Knox et al^{18O} when they evaluated bone regeneration around hydroxyapatite-coated implants exhibiting standardized dehiscence and intra bony defects.

Positive clinical results have been reported with the use of hydroxyapatite-coated implants in association with maxillary sinus augmentation. Kent and Block²¹ placed 45 hydroxyapatite-coated implants in the grafted sinuses of 11 patients. Implants and bone grafts were placed simultaneously in all patients. Follow-up periods were from 12 months to 4 years. At the time of exposure, all of the implants were nonmobile. During the entire study period, not a single implant failed. In another investigation, Tidwell et al⁴ placed 203 hydroxyapatite-coated implants in grafted maxillary sinuses. Only thirteen (6.4%) of 203 implants failed.

Small et al^{PO} reported findings similar to those of Kent and Block.²¹ The authors placed 111 implants in 45 grafted sinuses. None of the implants was lost during the study period.³⁰

These findings are in agreement with those of an experimental study of our group performed in the monkey,⁴⁶ where all implants successfully integrated at the histologic and clinical level, and where the loaded implants were maintained throughout the entire 6 months of loading. Loading exerted a positive influence on the amount of mineralized bone-to-implant contact. A slight loss of crestal bone loss was noted in the loaded implants. The amount of bone loss was comparable to that reported in an experiment in the beagle dog, where loading of dental implants after placement of prostheses demonstrated similar results over a 6-month period.⁸¹

The assumption that hydroxyapatite-coated implants may form a chemical fixation to the living bone, with a strength comparable to that of cortical bone itself,⁸² was the main reason for such a surface-design concept. Because this bioactive bond is mediated by continuous ion exchange,⁸³ there has been some concern regarding the propensity for the hydroxyapatite surface to dissolve.⁸⁴ Dissolution characteristics of hydroxyapatite are governed by a series of material properties such as crystallinity, chemistry, density, and secondary phases.⁸⁴ Thus, commercially available hydroxyapatite-coated dental implants are not all coated by the same manufacturer and can vary significantly. Dental implant surface coatings can fail if they are not of sufficient quality to withstand the functional requirements of the physiologic environment of the living body. Long-term negative effects such as fracture, separation, and dissolution should be determined for all types of hydroxyapatite coatings. In the monkey study,⁴⁶ the hydroxyapatite coating of the IMZ cylinder implants used did not show signs of dissolution.

A controversy still exists regarding whether to place implants simultaneously with the sinus graft procedure or to delay their placement. A main point of agreement is that an implant should not be placed simultaneously with a sinus augmentation procedure if primary stability cannot be achieved. The faster rate of osseointegration, together with the greater percentages of osseointegration, observed in hydroxyapatite-coated implants (as opposed to titanium implants)^{64,85-88} indicates that hydroxyapatite-coated types may be beneficial in simultaneous implant placement procedures.

Because there is a controversy regarding the properties and characteristics of hydroxyapatite-coated implants, long-term clinical and histologic evaluations of different hydroxyapatite coatings are still necessary before this type of implant can be recommended for rehabilitation of the posterior edentulous maxilla.

The Intramobile Element in a Sinus Graft with Porous Hydroxyapatite

The biomechanical concept of the intramobile connector is to mimic the natural tooth unit in functional situations, such as during normal mastication or during sudden impact loads exhibited in the chewing of hard objects. The periodontal ligament and natural body fluids contained in the bone dampen these forces. The supporting and surrounding anatomic and physiologic structures are designed to provide a dampening of the transmission of peak stresses in the natural dentition. Hence, the underlying bone is not damaged due to high stress.

The mechanical and biomechanical forces applied to the implant-restored suprastructure vary with time as a result of masticatory function. Certain sudden impact forces, such as those encountered during chewing of a hard object, are unavoidable. When the suprastructure is supported by an endosseous implant without stress relief, the rate of increase of the force is very rapid because of the limited elasticity of the bone with which the suprastructure is rigidly connected. This dynamic load transfer is stopped by neurophysiologic mechanisms. However, the stress level generated at the implant-bone interface is beyond the critical threshold.

The intramobile connector imitates the viscoelastic properties of the periodontal ligament. Over the last two decades, clinicians have gained extensive experience by applying the intramobile technology. The intramobile element is designed to transfer peak stresses into a gradual stress distribution on the endosseous implant. When the intramobile connector is incorporated in the suprastructure, biomechanical analysis reveals that the stress transmitted to the bone-implant interface is greatly reduced. This has been demonstrated in both

in vivo and in vitro studies.⁸⁹

To allow rigid splinting of an osseointegrated implant to a natural tooth and its suspensor system (periodontalligament), a mechanism for stress absorption and distribution within the implant is required. It is hypothesized that if a rigid fixed prosthesis is supported by both a natural tooth and an ankylosed implant, one of several phenomena could take place: (1) because of the high modulus of elasticity of the element that helps secure the fixed partial denture to the natural tooth, the cement bond could fail when stressed by the rigid-flexible combination and eventually micromovement of the retainer on the natural tooth could create continuous microtrauma, resulting in complications to the natural tooth; (2) if the prosthesis was exceptionally long, flexure of the metal substructure could result in fracture of the ceramic veneer, if present; or (3) bone could resorb, around the implant, the natural tooth, or both.

Just as the overloading of a natural tooth is partially moderated by proprioceptive control through the periodontal ligament and its nerve receptors, the level of stress at the bone-implant interface can likewise be controlled by a shock-absorbing element designed to simulate the function of the periodontal ligament. The intramobile element for the IMZ system is made of polyoxymethylene (Delrin). This material was originally introduced in 1960 by DuPont de Nemours and has subsequently been used in both the cardiovascular and orthopedic fields. Its use is indicated in clinical situations where strength, rigidity, fatigue, wear resistance, toughness, and elasticity are significant requirements. Extensive testing of the intramobile element has been carried out to demonstrate that after 500 days of simulated use, the dimensional changes did not exceed 0.0127 mm. Therefore, with this exceptional dimensional stability, it is assumed that minimal change would occur at the occlusal level with constant use.

Because most polymers are not as durable as metals, however, the intramobile element does require periodic replacement. The recommended period for clinical use is 12 months. Although this time period is considered prophylactic and empirical, the actual critical fatigue time for the intramobile element is dependent on many factors. Among these are the age and physical condition of the patient, the strength and health of the masticatory musculature, the opposing dentition, and the materials used in the prosthesis.

The effect of loading at the implant-augmented bone interface was also analyzed in a recent experimental study.⁴⁶ Because a greater percentage of new bone was found on the implant surfaces in both the remaining bone and in the augmented areas on loaded implants, it can be assumed that loading stimulated bone remodeling.⁹⁰ Thus, the new implant bed seemed to react to occlusal forces according to Wolff's law.⁷⁴ Han and Han⁹¹ evaluated the shear strength against push-out forces applied to plasma-sprayed implants placed in an implant bed reconstructed out of porous hydroxyapatite or in sound bone. The authors found that the mean shear strength of the bone-implant interface in sound bone was not significantly different from the shear strength of the implant bed reconstructed out of porous hydroxyapatite.

In conclusion, the use of intramobile connectors in conjunction with a sinus graft using porous hydroxyapatite results in long-term, predictable restorations in highly loaded regions of the posterior maxilla.

Discussion

The aim of a 5-year clinical investigation of our group⁹² was to determine the long-term clinical outcome and predictability of the maxillary sinus augmentation procedure. Two porous hydroxyapatites were used with and without autogenous bone particles. The augmentation materials evaluated were a bovine-derived porous hydroxyapatite alone (Bio-Oss), porous coralline hydroxyapatite alone (Interpore), a combination of both hydroxyapatites (Bio-Oss mixed with Interpore in a 1:1 ratio), Interpore mixed with autogenous bone from the iliac crest (in a 1:3 ratio), and Interpore mixed with autogenous bone from the chin (in a 1:1 ratio). A total of 340 plasma-sprayed cylinder implants were placed either simultaneously with the sinus augmentation procedure (235 implants) or 6 months after the procedure (105 implants) in 133 patients with insufficient bone volume in the posterior maxilla.

The implants were restored with a total of 151 fixed-detachable ceramometal prostheses and evaluated for up to 5 years. Clinical evaluations included yearly assessments of peri-implant inflammation, implant mobility, and clinical attachment levels. Radiographs were also taken prior to the sinus augmentation surgery, at abutment connection, at completion of the restoration, and, thereafter, at yearly intervals.

All of the implants (100%) placed into the augmented sinuses achieved osseointegration. Only four implants (1.2%) failed to maintain osseointegration after prosthesis placement, yielding an implant survival rate of 98.8% over the entire course of the study. Of the 340 implants, 307 (90.3%) were considered successful according to the success criteria stipulated in the inves-

tigation, ie, absence of implant mobility and peri-implant radiolucency, crestal bone loss less than 1.5 mm during the first year and less than 0.2 mm per year afterward, and absence of any other clinical signs and symptoms associated with failure such as pain, swelling, or infection. The patient's gender, the length and localization of the implant, the remaining bone height, and the type of bone-augmentation material had no effect on implant success. None of the 151 fixed ceramometal prostheses was lost during the observation period. The results of this study⁹² support the long-term clinical predictability of maxillary sinus augmentation procedures for the rehabilitation of the edentulous posterior maxilla with implant-supported prostheses. An 8-year follow-up of the clinical study has been recently completed and shows similar results.⁹³

The quality and quantity of bone for implant placement after sinus floor elevation and augmentation were

evaluated in an histomorphometric study in 21 patients and 59 specimens.⁴⁷ The mineralized bone-to-implant contact in the augmented area was 26.0% with Interpore, 30.0% with autogenous bone plus Interpore, 30.0% with Altipore, and 34.0% with autogenous bone plus Altipore.

Similar results were evaluated in a more recent histomorphometric study.⁹⁴ Three different porous hydroxyapatite material for maxillary sinus floor augmentation in humans were studied in 94 patients and 157 specimens. Comparison of the percentage of new, mineralized bone in the augmented areas showed the following results: 27.8% with Interpore, 24.5% with intraoral bone plus Interpore, 26.0% with BioOss, 22.0% with intraoral bone plus Bio-Oss, 20.8% with Interpore plus Bio-Oss in a 1:1 ratio, 37.0% with intraoral bone plus Altipore.

It is well known that the placement of a suprastructure on dental implants causes slight peri-implant crestal bone loss.^{4,81,95} The same effect was found on the implants placed in the augmented sinus in our experimental and clinical studies. It is unknown, however, if this is an effect of loading or if it is caused by the abutment connection procedure.

The optimal time for placing implants in the augmented sinus is not known today. It is obviously beneficial for the patient if the dental implants are inserted simultaneously with the sinus augmentation procedure. The data from experimental studies performed by our group have shown that delayed implant placement results in a greater percentage of bone apposition on the implant surface in the augmented area under loaded and unloaded conditions. Many authors have favored the simultaneous placement of implants in combination with autogenous bone onlay grafting in the partially edentulous patient⁹⁶ as well as in the completely edentulous patient.⁹⁷⁻⁹⁹ Other investigators have preferred delayed implant placement,^{17,100-101} in part because it guarantees better implant positioning for the prosthetic reconstruction.^{100,101} Jensen and Greer²³ and Jensen¹ recommended delayed placement, while Khoury et al⁶⁵ advocated immediate implant placement.

Despite the persistent controversy, it is apparently agreed, from a clinical point of view, that primary stability of the implant is the main criterion to determine if simultaneous implant placement is possible. Thus, if not enough bone volume remains to provide implant stability, delayed implant placement should be considered. The histologic findings of our experimental studies indicate that, in some cases, delayed implant placement may be a better treatment alternative than simultaneous implant placement.

Conclusion

None of the three bone-grafting materials or combinations was determined to be statistically superior to the other. These clinical and experimental results are encouraging, because they indicate that it is not absolutely necessary to harvest autogenous bone to attain predictable long-term results with the sinus augmentation procedure.

It has been proposed that a slight intrasinus pressure normally exists within the sinus cavity. This pressure could theoretically cause bone resorption and antrum re-pneumatization after an augmentation procedure and, therefore, reduce the bone mass sufficiently to cause endosseous implant failure under normal biomechanical loads. The results of our investigations showed no apparent clinical effect of this intrasinus pressure. Thus, it appears that, if the implants are osseointegrated and the bone is stimulated within physiologic limits, an adequate bone volume will remain to carry the imposed load.

The study described in this chapter supports the employment of porous hydroxyapatite as a bone grafting material for maxillary sinus augmentation procedures. The porous bovine-derived hydroxyapatite and the porous coralline biomaterial were found to be biocompatible and enhanced bone formation and implant osseointegration in the augmented sinus areas, resulting in an implant bed that reacted positively on loading by responding with a normal bone-remodeling process.

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Histologic Aspects of Simultaneous Implant and Graft Placement

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Bone graft augmentation is commonly used in an effort to increase the bone support for oral implants. The incorporation of the graft and the integration process of the implants are both complex healing situations and must result in a direct contact between the implant and remodeled grafted bone for the augmentation procedure to be meaningful. Various grafting regimens have been described, and the simultaneous placement of graft material, most frequently autogenous bone grafts, and implants has been advocated.¹⁻²¹ Although acceptable clinical results have been reported based on survival analysis, it is not known to what extent the achieved implant stability is a result of integration with the graft material.

Histologic examination of the graft-implant interface is needed to verify if and when integration occurs for different surgical approaches and graft materials. A number of studies have presented the histologic analysis of human biopsy specimens from the maxillary sinus after augmentation with various materials,²²⁻²⁵ however, except for some case reports,⁶⁻²⁹ few clinical studies that include histologic analysis of the tissue-implant interface from consecutive patients have been presented to verify that osseointegration of the implant occurs in the grafted material.³⁰⁻³² In this chapter, the biology of the implant-bone graft interface is discussed from a histologic point of view, based on the results of our own work and reports found in the literature.

The Implant-Bone Interface in Normal Bone

The surgical trauma when an implant site is prepared provokes a preprogrammed healing response that aims at complete repair of the defect by formation of new bone, remodeling, and maturation. When an implant is placed in the defect, the result of the healing will either be formation of an intimate contact between bone and the implant surface, also known as *osseointegration* (Fig 8-1), or soft tissue encapsulation, which is considered failure³³ (Fig 8-2). The end result of the healing is determined by factors such as implant biocompatibility, implant design and surface topography, surgical techniques, state of the host bone, and the loading conditions.³⁴

The clinical titanium-bone interface of 33 implants retrieved from patients 6 months to 16 years after placement was studied by Albrektsson and coworkers.³⁵ By means of light microscopic morphometry, these authors described a mixed interface, ie, the presence of mineralized bone, bone marrow cavities, and vessel channels, which reflected the normal morphology of bone. The measured direct bone-implant contact was, on average, 84.9%. Further analysis of retrieved implants revealed a lesser degree of bone-implant contacts for unloaded implants (Fig 8-3) and for implants loaded up to 1 year (about 40%) than for implants loaded for longer peri

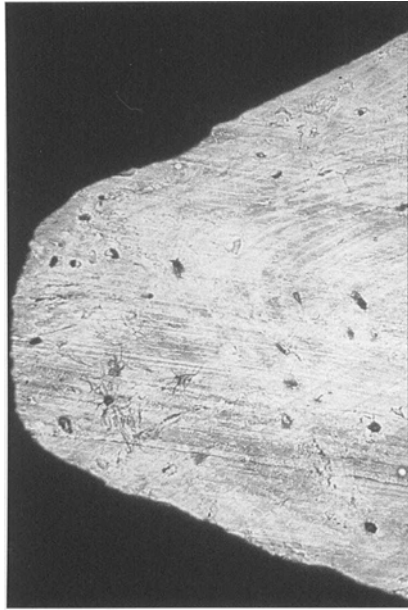


Fig 8-1 Histologic appearance of a clinically stable commercially pure titanium implant after several years of loading in the mandible. Mature cortical bone is in intimate contact with the implant surface.

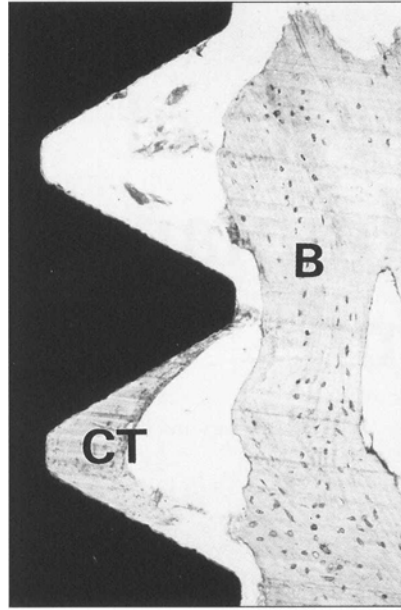


Fig 8-2 Histologic appearance of a clinically mobile implant. A fibrous connective tissue (CT) separates the bone (B) and the implant surface.



Fig 8-3 Histologic appearance of an unloaded mandibular implant retrieved 6 months after placement. The interface is occupied by connective tissue and newly formed bone, which can be distinguished from the original cortical bone by a demarcation line (arrows). Thus, the healing and maturation of the interface bone have not been completed.

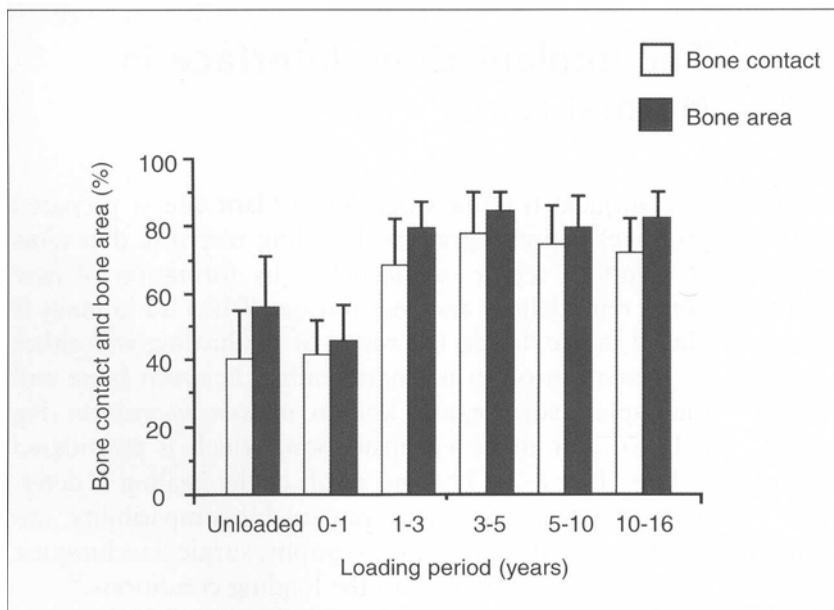


Fig 8-4 Morphometric measurements of 60 clinically retrieved commercially pure titanium implants. The amount of bone at unloaded implants and implants loaded for up to 1 year is less than that at implants with longer loading periods. There is a statistically significant difference between unloaded implants and implants with a loading period of 1 year or longer and between implants loaded less than 1 year and the latter. There is no significant difference between unloaded and implants loaded less than 1 year.

ods (about 70% to 80%)³⁶ (Fig 8-4). This is in line with the assumption that healing, remodeling, and maturation may take 12 months or longer.³⁷

For the same implant design and surface topography, the stability is related to the biomechanical properties of the adjacent bone and the degree of bone-implant contact.³⁸ This means that a time dependence is at hand, because, during healing and remodeling, the degree of bone-implant contact and maturation of the bone will increase.^{38,39} Resonance frequency

analysis has revealed an increase in stability for maxillary implants from implant placement up to 1 year in function,⁴⁰ which is consistent with previously described histologic findings.³⁶ Clinical experiences with threaded titanium implants show that sufficient implant stability for long-term function of most implants is achieved during 3 months in the mandible and 6 months in the maxillae, although implants placed in soft bone may need longer healing periods.⁴¹

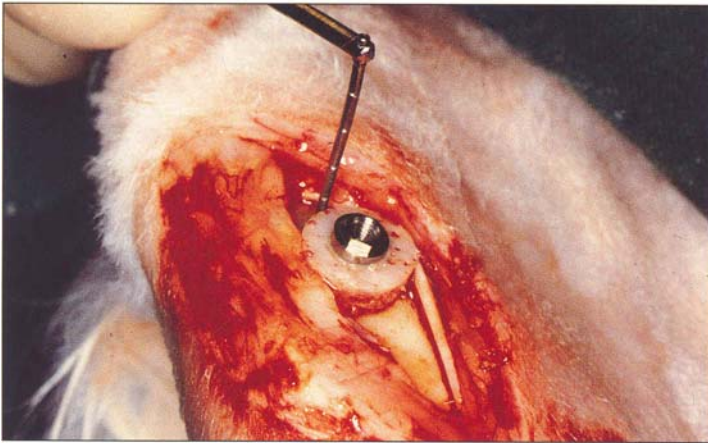


Fig 8-5a Titanium implant placed simultaneously with an autogenous onlay graft from the skull in the rabbit tibia. A control titanium implant without a bone graft was placed on the contralateral side.

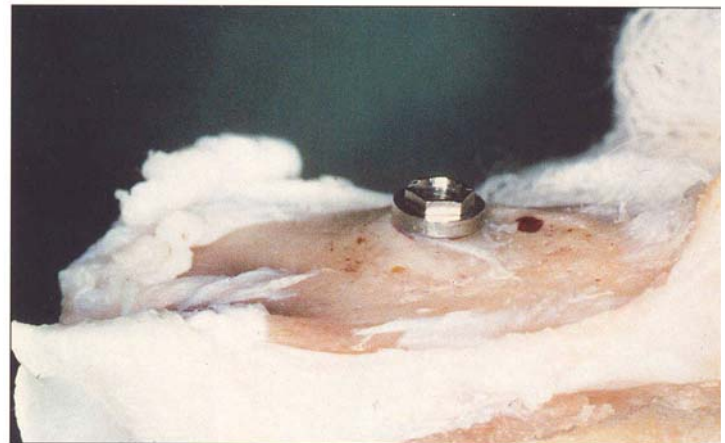


Fig 8-5b Clinical appearance after 24 weeks of healing. Changes in volume resulting from resorption and remodeling are evident, but no implant threads are visible.

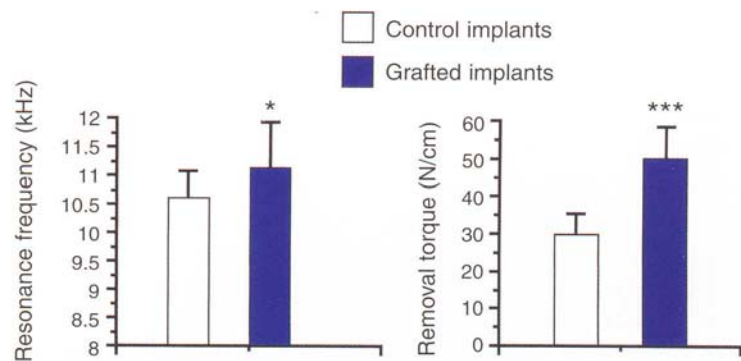


Fig 8-5c Resonance frequency measurements and removal torque tests 24 weeks postoperatively. The grafted implants were significantly more stable than the controls. * $p < .05$. *** $p < .001$.

The Implant-Tissue Interface in Augmented Bone

Unlike in normal bone, the preparation of an implant site in a free bone graft will probably not provoke a repair process, because of the interrupted microcirculation and rapid cell death. Nevertheless, the host bone, the residual alveolar crest, will respond to the surgical trauma and initiate a healing process that will lead to integration of the part of the implant in the residual bone and incorporation of the bone graft. If it survives the early period of healing and loading, the implant will eventually integrate with the grafted bone, as indicated by the histologic evidence discussed next.

Experimental studies

Experimental studies suggest that implants will integrate with particulate or block autogenous bone

grafts.⁴²⁻⁴⁷ For instance, Neukam and coworkers⁴² demonstrated integration of screw-shaped titanium implants in free autogenous onlay grafts inserted in the mandibles of 10 minipigs. New bone formation and a direct contact between the grafted bone and the implants were observed after 3 and 5 months. In a dog model, Lew et al⁴³ showed that osseointegration of titanium implants developed more rapidly in corticocancellous bone blocks than in particulate bone grafts. Recently, Rasmusson et al⁴⁴ showed that titanium implants, placed simultaneously with an autogenous onlay bone graft in the rabbit tibia, integrated with the graft which gave them greater stability compared to ungrafted controls (Figs 8-5a to 8-5c).

Allogeneic and alloplastic materials also have been tested in conjunction with implant placement.⁴⁸⁻⁵⁰ The integration of titanium implants in dog alveolar ridges augmented with allogeneic demineralized and lyophilized dentin or bone was evaluated by Pinholt et

al.⁴⁸ A total of 32 titanium implants were placed in the

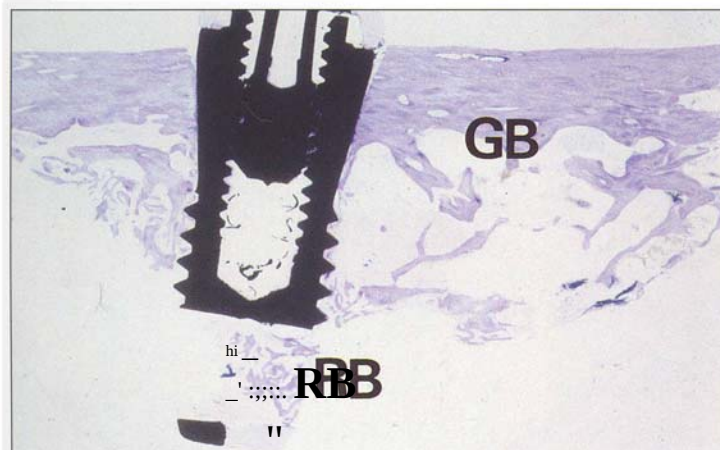


Fig 8-6a Histologic appearance of a commercially pure titanium implant removed 4 weeks after simultaneous placement with a free autogenous iliac crest bone graft. There are no signs of bone resorption or bone formation in the grafted bone (GB) at the coronal part of the implant. However, in the apical part, bone formation has occurred in the recipient site bone (RB), which has been trapped in the apical hole of the implant.

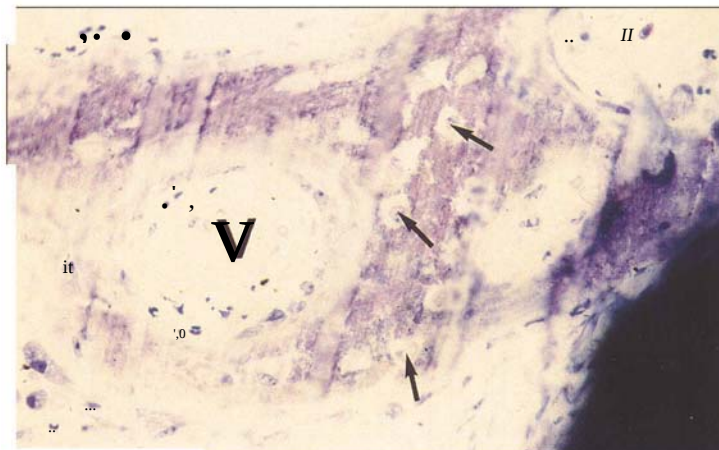


Fig 8-6b Bone formation is evident near the implant surface in the residual alveolar bone. Some of the osteoblasts are being entrapped in mineralized bone matrix (arrows). (V) Vessel.

augmented regions of 10 dogs 5.5 months later and followed for another 3.5 months. All implants were encapsulated by a fibrous tissue containing multinuclear giant cells and other inflammatory cells. The graft material generally showed no signs of remineralization except when they were in contact with the recipient bone surfaces. This is in line with the findings of Becker et al,⁴⁹ who reported poor results of using demineralized freeze-dried bone and membranes for regeneration of bone at implants. On the other hand, Jensen and coworkers⁵⁰ demonstrated in the canine mandible that direct bone-implant contacts were established when demineralized freeze-dried bone and membranes were used. They also used autogenous bone grafts and concluded that these perform better than the allograft material.

Histology of clinically retrieved routine implants

Reports with histologic analysis of the human bone graft-implant interface are rare.²⁶⁻²⁹ Histologic specimens were taken from a patient who died 8 months after sinus floor augmentation with freeze-dried allograft and resorbable hydroxyapatite and placement of two implants.^{26,27} One implant showed bone in the interface, while the other had a minimal amount of bone adjacent to the surface. The authors concluded that 8 months would not have been a sufficient healing period to allow loading of the implants.

Nystrom et al²⁸ presented a histologic analysis of one patient who died 4 months after an onlay grafting procedure and immediate placement of six implants ad

modum Branemark. The grafted bone from the iliac crest demonstrated signs of resorption but also areas where new bone formation was visible on old trabeculae. There was only a patchy contact between the grafted bone and the implants because the major part of the interface consisted of soft tissues, which contradicts the experimental findings described earlier.

Analysis of 19 clinically retrieved implants from simultaneous grafting procedures with autogenous bone has been performed at our laboratory (unpublished data) (Figs 8-6a and 8-6b). The mean loading periods were 2.6 years in the mandible and 4.7 years in the maxilla. The mean bone-implant contact was about 70% in the mandible and 60% in the maxilla. However, that included the total bone-implant interface, and it was most difficult to distinguish between grafted bone and residual bone (Figs 8-7a and 8-7b). Moreover, the specimens were not from consecutive patients and represented varying times of follow-up.

Histology of clinically retrieved microimplants

For better understanding of the healing process of titanium implants in bone grafts, there is a clear need for controlled clinical investigations, including histologic analysis of the bone graft-titanium interface in consecutive patients. For this purpose, a novel clinical technique comprising the placement and subsequent retrieval of commercially pure titanium microimplants has been developed³⁰⁻³² (Figs 8-8a to 8-8d). The screwshaped micro implants produced so far have typically been 2 mm in diameter and 6 to 9 mm long.

Fig 8- 7a Histologic appearance of a commercially pure titanium implant retrieved from a patient 3.5 years after a grafting procedure with simultaneous placement of implants and a free autogenous iliac crest bone graft. Bone resorption has occurred to the first thread (*bottom arrow*). The conical part was presumably submerged in the grafted bone at implant placement; about 5.0 mm of the grafted bone has been lost during the 3.5 years. (*Top arrow*) Presumed original marginal bone level; (*bottom arrow*) present marginal bone level.

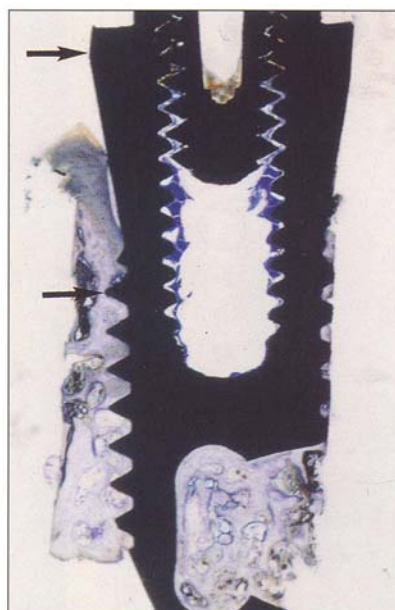


Fig 8- 7a

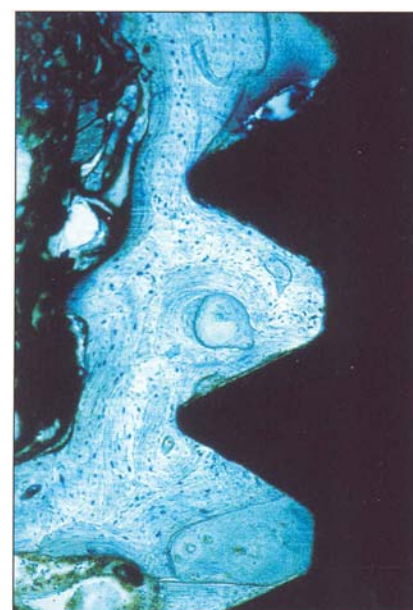


Fig 8- 7b

Fig 8- 7b Higher magnification of the first threads, which are occupied by mature lamellar bone. However, it is difficult to judge if this bone originates from the grafted bone or from the residual alveolar crest.

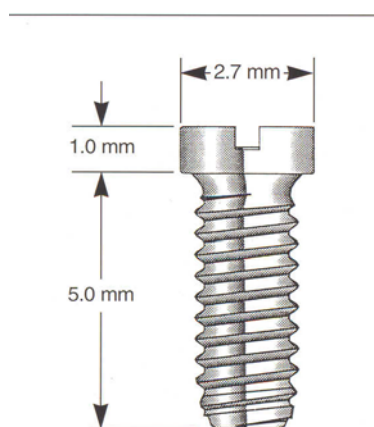


Fig 8-8a Most recently used micro-implant made of commercially pure titanium.

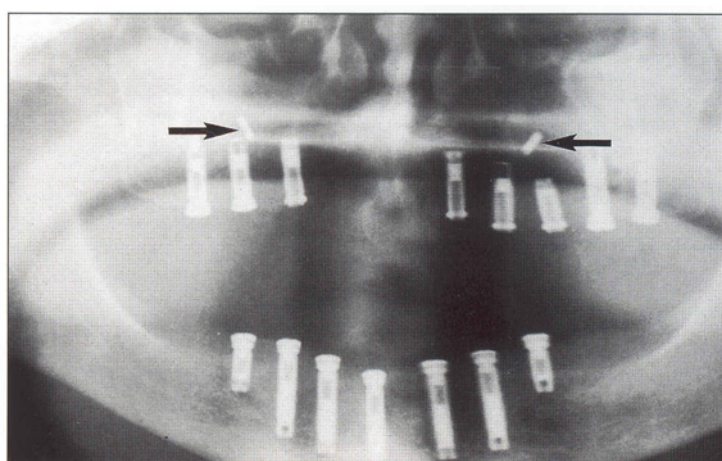


Fig 8-8b Radiograph of a patient treated with implants and bilateral maxillary sinus floor augmentation. Note the microimplants (*arrows*).

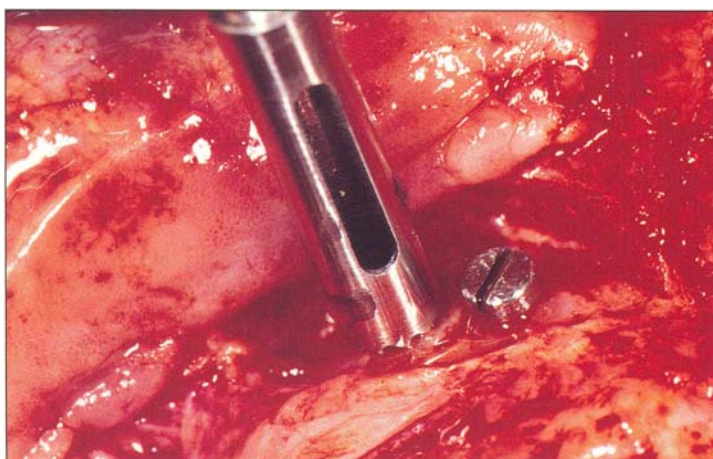


Fig 8-8e Retrieval of a microimplant 6 months after placement in an intra positional autogenous bone graft in the maxilla.



Fig 8-8d Clinical appearance of a trephined specimen.

Fig 8-9a Histologic appearance of a microimplant retrieved 6 months after simultaneous placement with radiated mineralized cancellous allograft in the maxillary sinus. Most of the implant surface is in contact with loose connective tissue.



Fig 8-9b Higher magnification of Fig 8-9a, showing a patchy bone-implant contact in the passage of the lateral wall of the sinus cavity and regeneration of the sinus wall bone along the implant surface (arrows).

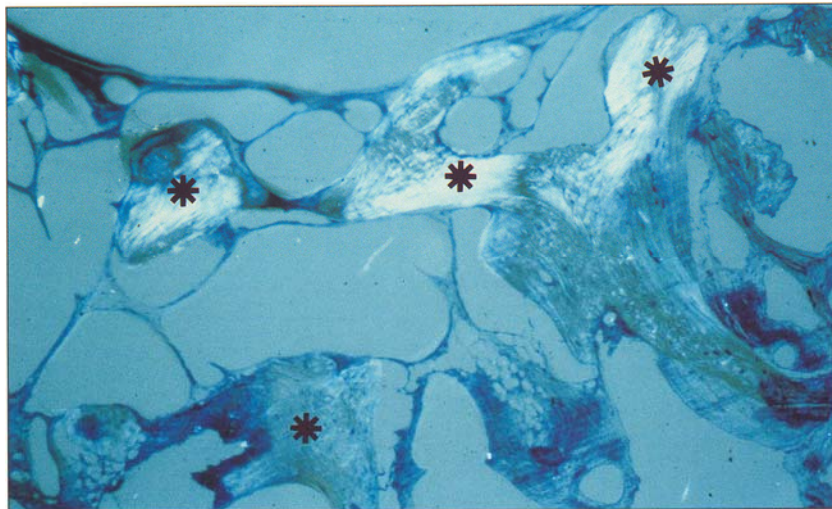


Fig 8-9c Magnification of the apical part of Fig 8-9a, showing (in polarized light) nonviable allograft particles (*) in a loose connective tissue. The implant is visible at the top.

The implants have been used to study the integration process in maxillary sinus floor augmentation with radiated mineralized cancellous allograft or autogenous bone³⁰ as well as in onlay and in intrapositional bone grafts from the iliac crest.³¹ The microimplant technique has also been used to study integration in extraction sockets grafted with demineralized 'freeze-dried bone allograft, xenogenic bovine bone, and autogenous bone.³² The implants have been placed in conjunction with the grafting procedure and retrieved with a trephine drill 3 to 14 months later, or have been placed after a 6-month primary healing of the bone graft with retrieval 6 months later. The specimens were kept in 4 % formaline and brought to our laboratory for further histologic processing, including dehydration and embedding in light-curing resin. Ground sections with a thickness of

about 150 μ m were produced for microradiography and thereafter ground to about 10-11 μ m thickness. The histologic analysis included morphometric measurements of the degree of bone-implant contacts as well as the amount of bone filling the implant threads.

Maxillary sinus floor augmentation with particulate autogenous and allogeneic bone grafts

In nine patients who were to receive sinus floor augmentation, six micro implants were placed with particulate autogenous bone grafts and six were placed with radiated mineralized cancellous allograft.³⁰ In the allografted sites followed for 6 months, various amounts of bone and allograft were present in an atypical, loose

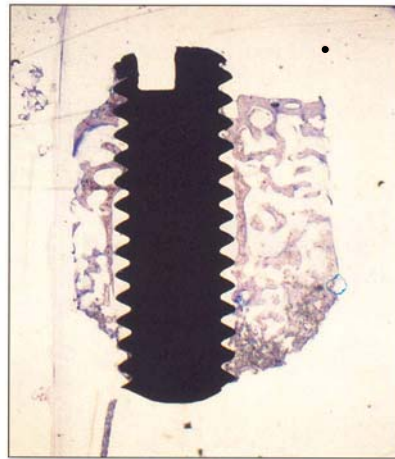


Fig 8-10a Histologic appearance of a microimplant retrieved 6 months after simultaneous placement with autogenous bone grafts in the maxillary sinus. Bone-implant contacts are visible in the passage of the lateral sinus wall but not in the grafted area. The grafted bone has a normal bone morphology, unlike the allografted specimens in this study.

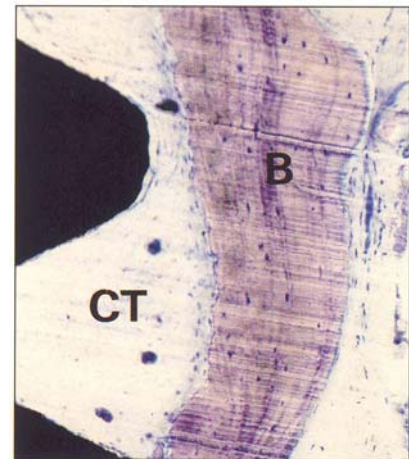


Fig 8-10b Magnification of Fig 8-10a, showing formation of lamellar bone (B) at a distance from the implant surface. (CT) Fibrous connective tissue.

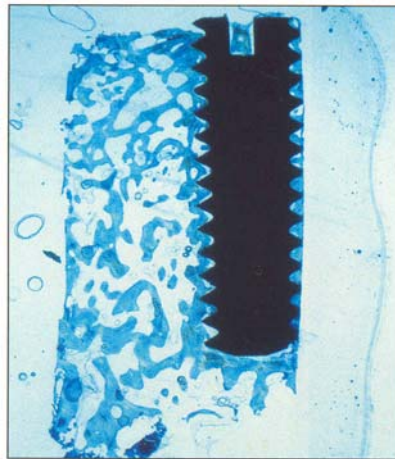


Fig 8-11a Histologic appearance of a microimplant retrieved 12 months after simultaneous placement with autogenous bone grafts in the maxillary sinus. The bone is denser and more mature than in the 6-month specimens.

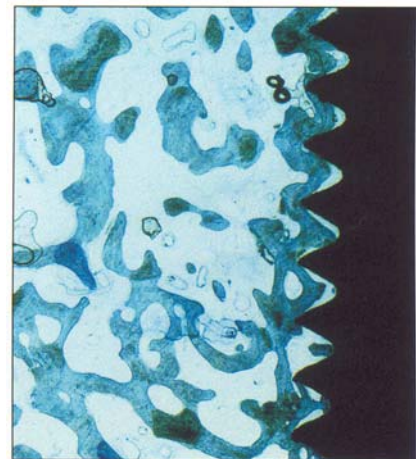


Fig 8-11b Magnification of Fig 8-11a. A high degree of bone-implant contacts is visible in this specimen.

connective tissue (Fig 8-9a). Most of the implant surface was in contact with the connective tissue. The majority of the specimen comprised nonviable allograft particles. Negligible amounts of bone were found in the implant threads situated in the graft (Figs 8-9a and 8-9b), while viable bone was present in the threads that penetrated the lateral sinus wall (Fig 8-9c). This was also the only location where direct bone-implant contacts were observed. The newly formed bone found in some specimens in the grafted area originated from the lateral sinus wall and followed the implant surface.

In an allografted site followed for 14 months, nonviable allograft particles still constituted about 50% of the total bone area. Although a large amount of bone was present outside this implant, a low degree of bone-implant contact was observed within the threads of the

implant in the grafted area, and most contacts were in the residual bone of the lateral sinus wall.

The autografted sites showed a normal bone morphology of viable trabecular lamellar bone interspersed with normal marrow tissue after 6 to 7 months of healing (Fig 8-10a). Active bone formation was evident on the grafted bone particles. The implant threads were filled with newly formed bone to higher degrees than at the allografted sites. However, except in the cortical passage, bone was only occasionally found to be in direct contact with the implant surface in the grafted area (Fig 8-10b).

Two autografted specimens followed for 11 to 12 months showed a more mature bone morphology than the 6- to 7-month specimens (Figs 8-11a and 8-11b). It was not possible to distinguish between the newly

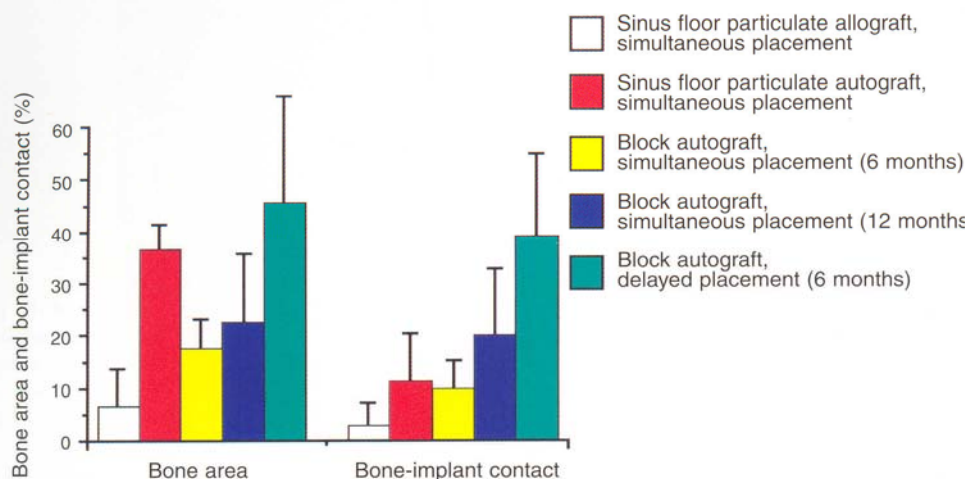


Fig 8-12 Morphometry of microimplant specimens from maxillary sinus floor augmentation with particulate allograft and autogenous bone grafts and from maxillary onlay and interpositional autogenous block bone grafts. For the former specimens, only the bone area and bone-implant contacts in the grafted area are presented.

formed and remodeled bone and the grafted bone particles, which seemed to have been fully incorporated and replaced by newly formed bone. More bone as well as higher degrees of bone-implant contacts were found for the autogenous bone graft specimens (Fig 8-12).

Maxillary jaw augmentation with onlay and interpositional autogenous corticocancellous bone grafts

Twenty-nine microimplants were placed in 10 patients who were to receive maxillary jaw bone augmentation with autogenous onlay bone grafts ($n = 6$) and intrapositional bone grafts placed in conjunction with a Le Fort I procedure ($n = 4$).³¹ Three microimplants were inserted and retrieved from each patient in such a way that specimens representing simultaneous placement with 0 to 6 and 0 to 12 months of healing, and a delayed approach with 6 to 12 months of healing, could be histologically analyzed. Light microscopic examination of the 6-month simultaneous specimens showed various amounts of cortical and cancellous bone, mostly grafted bone, and connective tissue (Fig 8-13a). The bone grafts clearly underwent revascularization, because a large number of vessels filled with red blood cells were present. Bone resorption had preceded revascularization and bone formation in the cortical compartment. Here, most of the newly formed bone was lamellar and deposited on the surface of the grafted bone (Fig 8-13b). Bone deposition was also seen on the trabeculae of the cancellous bone (Fig 8-14). Nonbone areas were occupied by a richly vascularized loose connective tissue with a morphology that resembled that of bone marrow.

The 12-month simultaneous specimens had a more mature appearance, although active bone formation could still be seen. Little bone occupied the implant sur-

face. The delayed-approach specimens, in general, showed dense lamellar bone, which occupied the implant threads to a high degree (Fig 8-15). Less grafted bone could be identified, which indicated more complete incorporation of the bone graft.

The morphometric measurements of 6-month simultaneous specimens showed that the implant threads were 17.6% occupied by bone (5.6% grafted and 12.0% new bone). Only 10.0% of the implant surface was in direct contact with bone (2.1% grafted and 7.9% new bone; see Fig 8-12). The overall impression was that 6 months after graft and implant placement still is early in the healing and incorporation process.

The degree of bone-implant contact and bone area for the 12-month specimens were 20.0% and 22.6%, respectively. The delayed-approach microimplants showed more bone-implant contact (39.1%) as well as more bone occupying the threads (45.5%).

Conclusion

The studies on simultaneously placed microimplants and bone grafts revealed a low degree of osseointegration in the bone grafts after 6 months of healing (about 10% bone-implant contacts)^{30,31} compared with the clinical histologic appearance of clinically retrieved implants placed under normal conditions (about 40% to 85% bone-implant contacts).^{35,36} In spite of this, all ordinary implants (Nobel Biocare) placed in the maxillary floor augmentation study were clinically stable at the time of abutment connection and remained so after more than 3 years of functional loading.^{3°} This can be attributed to the support of the residual crestal bone, which in most cases was about 5 mm.



Fig 8-13a Histologic appearance of a microimplant 6 months after simultaneous placement with an autogenous onlay bone graft in the maxilla.

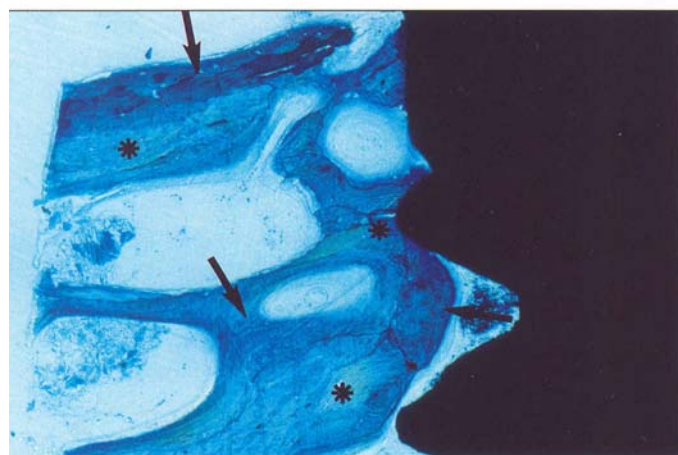


Fig 8-13b Magnification of 8-13a, showing bone resorption of the grafted bone (*) and formation of new bone (arrows), which reaches the implant surface at some points in the cortical passage.

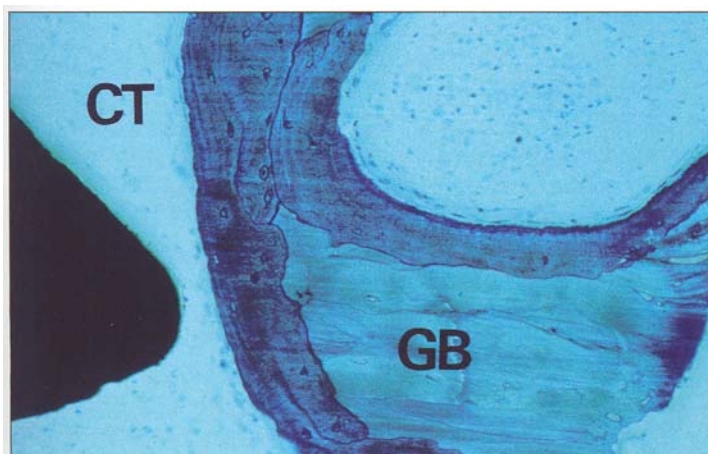


Fig 8-14 Histologic appearance of a microimplant 6 months after simultaneous placement with an autogenous onlay bone graft in the maxilla, showing active bone formation and incorporation of the grafted bone (GS). The implant interface is occupied by a loose connective tissue (CT), which has a morphology that resembles the morphology of bone marrow.

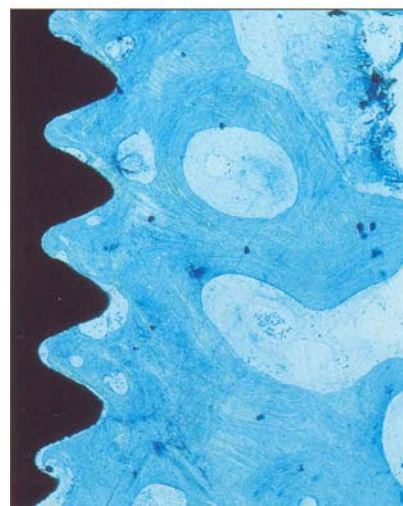


Fig 8-15 Histologic appearance of a microimplant placed 6 months after placement of an onlay graft in the maxilla and retrieved 6 months thereafter. Most of the implant surface is in contact with mature lamellar bone.

As previously demonstrated by Jensen and Greer,⁵ there seems to be a correlation between the amount of supporting residual bone and the loss of implants, irrespective of the kind of particulate graft used. In that study, the implant survival rate was only 29% when the residual bone was less than 3 mm (class D sites), while all implants were stable when the residual bone was 7 mm or more.⁵ Moreover, Jemt and Lekholm⁵ reported that the failure rate of short implants placed in severely resorbed maxillae was similar to that found for implants placed simultaneously with autogenous onlay grafts in the maxilla (20.0% to 28.7% vs 19.3%) after 5 years, which indicates that the bone-grafting procedure improved the clinical results only by a few

percentage points. Therefore, the efficacy of simultaneous placement of implants and particulate bone grafts to increase implant stability in the short term can be questioned.

The clinical histologic evidence from our studies favored the use of autogenous bone grafts but indicated that sufficient integration with simultaneous implant and graft placement is not achieved after 6 months of healing. Although few specimens were analyzed, the findings also suggested that the integration may be improved by longer healing periods. The sufficient healing period for a one-stage procedure is not known, but the major changes in onlay bone grafts in the maxilla seem to take place during the first 2 years after placement.^{14,21}

From a biologic point of view, an attractive approach is the use of a two-stage technique. 52-54 With this approach, the graft will have time to be revascularized, and the surgical trauma that occurs when an implant is placed later will most likely provoke an immediate healing response, similar to that in normal viable bone. Experimental⁴⁵ and clinical data⁵⁴ as well as our preliminary histologic analysis of two-stage microimplants also support this concept (Fig 8-15). However, the bone graft-implant interface has to be further examined in clinical studies to allow conclusions to be drawn about which technique is preferable, taking the clinical results, complications, and time and amount of surgery into consideration.

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Sinus Grafting with Calvarial Bone

Jean F. Tulasne, MD

The cranial vault has always been an extremely valuable source of bone grafts. Facility in harvesting, a simple postsurgical period, and solid construction make calvarial bone an ideal material for reconstruction of the cranial or facial skeleton.

Although bone from the cranial vault had been used as early as 1890 as part of an osteocutaneous flap by König¹ and Müller/ the first autogenous cranial bone graft was apparently performed by Dandy³ in 1929. Tessier,⁴ however, was the first to popularize the use of the calvarium as a donor site of grafts for cranial and facial reconstruction.

Grafting of the maxillary sinus floor was first described by Boyne and James.⁵ Results of maxillary sinus grafting using cranial bone in two thirds of the cases have already been published.⁶ This chapter will describe experience to date, consisting of 243 sinus grafts, of which 194 (79.8%) were cranial bone grafts. The other donor sites were the ilium (41 grafts; 16.9%), the chin (six grafts; 2.5%), and the tibia (two grafts; 0.8%). The purpose of the study is to show that the augmentation of the atrophied maxilla by grafting the sinus floor and the alveolar ridge with autologous calvarial bone ultimately enables secondary placement of endosseous implants with optimal long-term stability.

Method and Materials

From September 1990 to June 1997, 120 patients were operated on, representing a total of 194 maxillary sinuses grafted with cranial bone. The majority of patients were women ($n = 93$; 77.5%), with a mean age of 53 years (range of 25 to 77 years).

Sinus grafting was indicated in patients with missing maxillary posterior dentition and insufficient residual alveolar bone to provide long-term anchorage of implants. Therefore, patients presenting with a bone height of less than 7 to 10 mm receive grafts, but the bone density, the width of the crest in the buccopalatal plane, and the loading conditions for each patient are always taken into account. A pterygomaxillary implant (which provides very strong anchorage)¹⁻⁹ can also be considered as an alternative but only if the prosthetic construction is built on a minimum of three implants, except in the case of very short prostheses.^{8,9}

The procedure consists of a two-stage approach. The first stage is the reconstruction by maxillary sinus grafting. This was bilateral in 74 patients. The number of right-sided cases and left-sided cases was approximately equal in unilateral situations.

Reconstruction of the maxilla

The reconstruction consists of four successive steps: dissection of the sinus floor, harvesting of the cranial bone grafts, grafting the sinus floor, and reconstruction of the alveolar ridge.

The intervention takes place with the patient under general anesthesia administered via orotracheal intubation. It is imperative that any dental or sinus pathosis be treated before the grafting procedure. A panoramic radiograph and a computerized tomographic (CT) scan (coronal and axial views) with Dentascan software (General Electric) are necessary preoperatively to obtain precise information regarding the state of the sinuses, their walls, and, of particular interest, the floor.

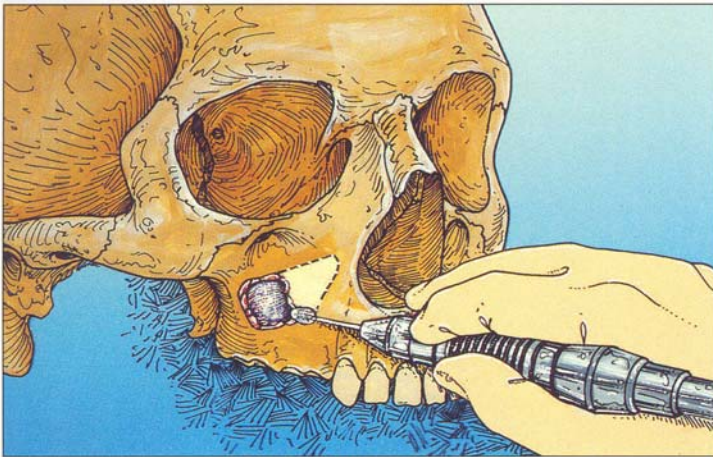


Fig 9-1 Exposition of the sinus mucosa through an anterolateral window.

The presence and localization of septa are noted. The patient is prepared, and a very limited zone of the scalp is shaved over the temporoparietal region (approximately 1.0 to 1.5 cm wide x 20.0 cm long).

Dissection of the sinus floor

The anterolateral area of the maxilla is exposed, either by a vestibular incision or, preferably, by an incision on the alveolar crest that is prolonged in the vestibulum via one or two vertical releasing incisions, thus creating a pedicled mucoperiosteal flap. The latter approach allows for a more precise and direct reconstruction of the alveolar region. The flap is raised by sharp dissection close to the bone surface.

A wide window is subsequently made with a large bur in the anterior wall of the sinus, until the sinus mucosa is exposed over a surface of approximately 2 cm² (Fig 9-1). The mucosa is elevated by careful dissection, initially from the entire floor of the sinus cavity, and then progressing to the lateral walls. If the sinus mucosa tears, the orifice is gently contoured with the dissector to prevent further tearing. Trying to suture the mucosa is, in my opinion, futile. The antrotomy window can be enlarged, if needed, to allow easier dissection of the mucosa. The floor and lateral walls of the sinus are completely cleared of all epithelial and fibrous debris by successive scratching of the bone surface with a rugine.

Harvesting of the cranial bone grafts

The harvesting is done in the parietal region, generally on the right side (nondominant hemisphere) behind the coronal suture, and approximately 3 cm lateral to the sagittal suture or midline of the skull. This is where the

sagittal sinus is located, constituting a significant risk. Preoperative skull radiographs are always used to determine the thickness and density of the vault, which can vary greatly from one individual to the next. Parietal bone is often thin immediately behind the coronal suture, but is progressively thicker toward its posterior part.

The incision of the scalp is made along a parasagittal axis, at the midpoint between the midline and the temporal crest, over a length of about 20 cm (which varies according to the quantity of bone needed) (Fig 9-2). The incision should be full-thickness to the bone, which is subsequently exposed by raising the pericranium.

Outertable grafts are harvested as follows: The outline of the proposed donor site is traced with an oscillating saw, held perpendicular to the skull, with special attention to the internal (medial) limit of this zone. Each graft is then contoured. The grafts are usually rectangular strips with a dimension of approximately 45 x 15 mm. The groove created with the oscillating saw is deepened down to the diploe with a bur.

The outer edge of the trough is feathered to facilitate the introduction of an osteotome between the inner and outer cortices, within the diploic space, and tangential to the surface of the vault. The splitting and elevation are done progressively, graft by graft, with a 10- or 15-mm straight osteotome. A narrower osteotome is used in the presence of brittle bone. A slightly curved osteotome is used when the splitting seems to progress toward the internal table (Fig 9-3). A minimum of three long, corticocancellous grafts are harvested for one sinus, and as many fragments or shavings of diploe as possible are obtained (Fig 9-4).

The peripheral edges of the donor site are beveled and smoothed, first with the osteotome and then with a large oval bur so that sharp bone edges will be less palpable through the scalp (Fig 9-5). The donor site is well irrigated, and usually no hemostasis is necessary. Bone wax may be conservatively applied to areas of brisk bleeding (emissary veins). Any full-thickness defects are covered with the remaining bone chips, which are held in place with a single sheet of an absorbable hemostatic gauze. Any dural tearing should be explored and managed appropriately. Scalp closure is accomplished in two layers after placement of a suction drain, and the area is covered by a sterile drape, which slightly compresses the region (Fig 9-6).

Grafting of the sinus floor

The construction is homogenous only if the sinus cavity is partitioned in its inferior part by a large graft that rests on the sinus walls and becomes the roof of the cavity to be filled. Thus, the sinus graft starts with the positioning of a large rectangular strip of cranial bone 10 to 15 mm above the floor. Before its insertion, the cor



Fig 9-2 Site for cranial bone graft harvesting.

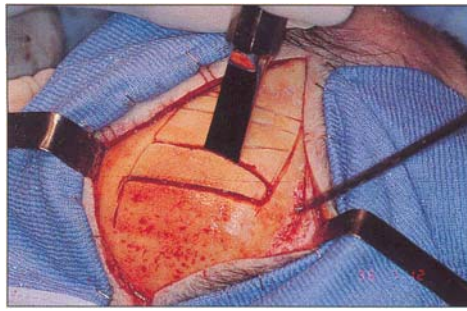


Fig 9-3 Splitting and elevation of rectangular (outer cortex) corticocancellous grafts.

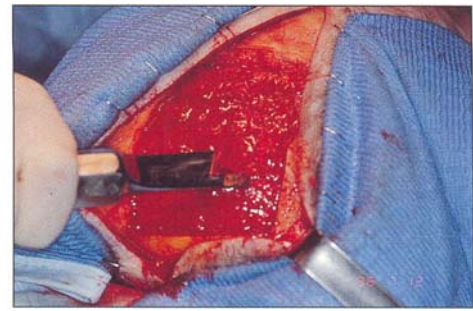


Fig 9-4 Harvesting of shavings of diploic bone with an osteotome.

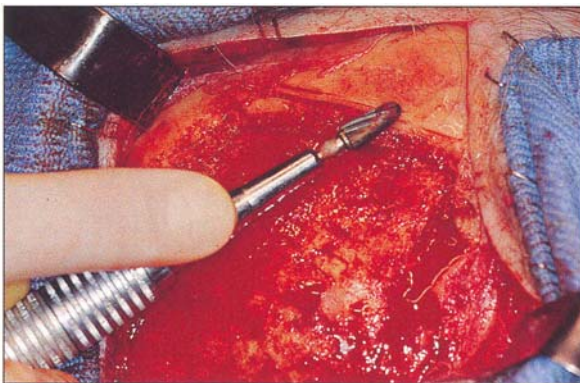


Fig 9-5 Smoothing of the peripheral edges of the donor site.

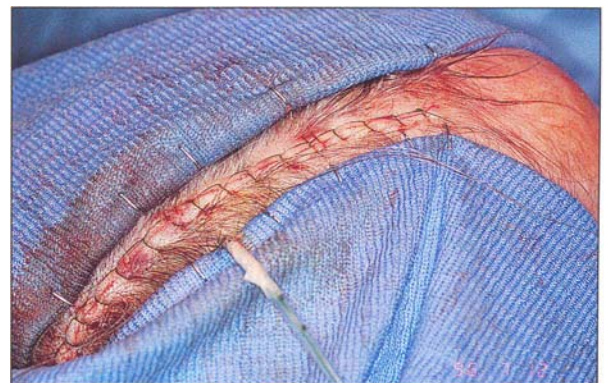


Fig 9-6 Scalp closure with suction drain.

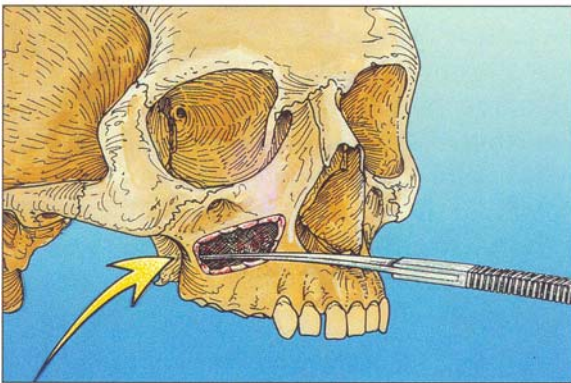


Fig 9-7 Formation of a trench in the posterior sinus wall with a chisel.

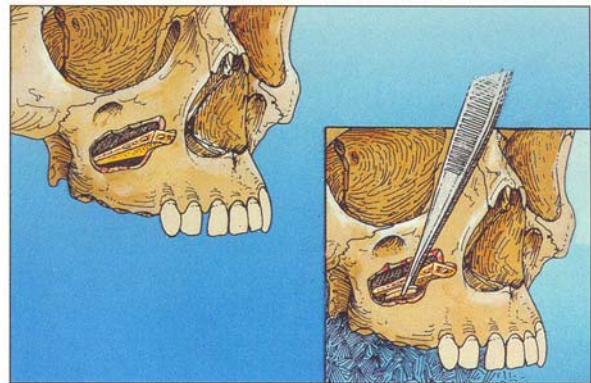


Fig 9-8 Sinus insertion of the transmaxillary graft and embedment in an anterior cutout notch. (Inset) Sinus packing with compressed bone fragments and bone chips.

tical side of the graft is thinned with a bur, and several holes are made to facilitate its revascularization.

One extremity is shaped to a triangular point so that it can be lodged in a trench previously created with a chisel in the posterior wall of the sinus as well as in the palatopterygoid bone mass (Fig 9-7). This graft is then placed in the sinus, gently forced in the posterior trench with a mallet, and embedded in a notch cut out in the anterior wall of the maxilla, more specifically in the canine pillar (Fig 9-8). In this manner, a perfectly stable assembly is accomplished.

"Chips," or small corticocancellous bone fragments, are used underneath the inserted rectangular strip to perfectly fill the cavity (Fig 9-8). To achieve this, the unused portions of the grafts are reduced to tiny fragments with a milling instrument, the Tessier osseomicrotome. These chips are tightly compressed until the space, limited by the floor of the sinus below and the transmaxillary graft above, is fully filled. Dead space must be avoided. The volume of the cavity is generally between 10 and 15 cm³.

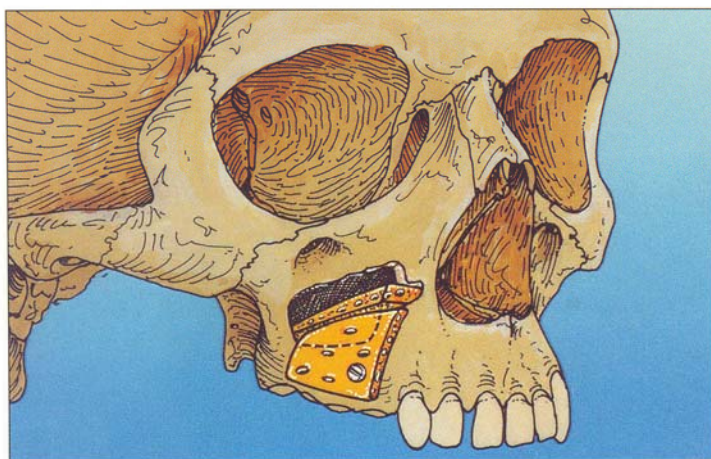


Fig 9-9 Onlay vestibular graft secured by one screw.

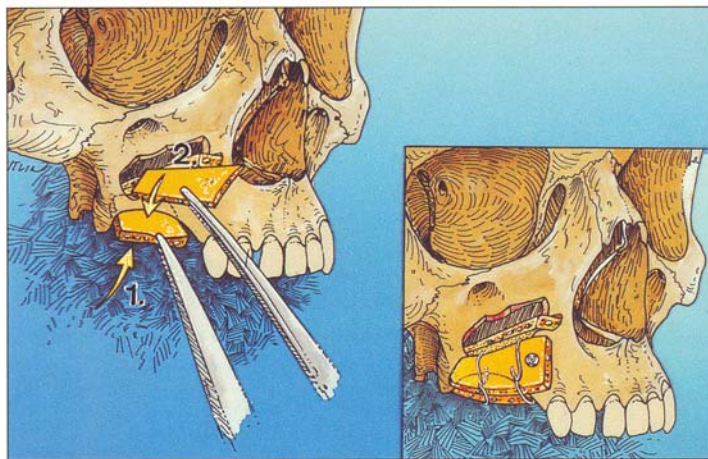


Fig 9-10 Ridge augmentation with two affixed onlay grafts, one palatal and one vestibular. (Inset) Immobilization at the base of the maxilla by circumferential double metal wiring and one screw.

Reconstruction of the alveolar ridge

A presurgical guide is made from the denture of the patient to evaluate the degree of atrophy of the alveolar region, which is more or less accentuated in the vertical plane but is constantly present in the horizontal plane. Therefore, an onlay vestibular graft is systematically affixed with its superior part closing the antrotomy window and resting under the external edge of the transmaxillary graft. The onlay graft is secured by one or two screws and is perforated in several places on its superior part opposite the intra sinus grafts (Fig 9-9).

In the presence of advanced atrophy of the alveolar ridge, it is necessary to affix two grafts, one palatal and one vestibular, with the cancellous sides facing one another and solidly immobilized at the base of the maxilla by a circumferential double metal wiring and additional screws if necessary (Fig 9-10).

The protruding edges of the bone graft are smoothed with a large bur, and all dead space is filled with fragments of diploe. The periosteum of the mucoperiosteal vestibular flap is incised at its base to mobilize it for perfect coverage of the grafts and for suturing without tension. Finally, a pressure dressing is applied around the head, and an elastic bandage is used to compress the operated maxillary area.

Postoperative period

The postoperative period is generally fairly simple, and little or no morbidity is associated. The patient usually experiences minimal discomfort. The dressing and suction drain are removed the day after the surgery, and the patient's hair can be washed. The patient can be released normally the day postoperatively with a 15-day antibiotic treatment, usually a penicillin or a penicillin derivative. Edema of the scalp is virtually nonexistent but can be more or less significant in the maxillary area. Sutures of the scalp are removed at least 10 days postsurgery. The partial denture is relined after 2 to 3 weeks, once the oral mucosa has healed.

Placement of implants

The second stage of treatment consists of the placement of implants (titanium screw-shaped Branemark implants [Nobel Biocare] in more than 80% of patients). The implants were inserted a minimum of 6 months following the calvarial grafting procedure and always after verification of the quality of the reconstruction of the maxilla by means of a CT scan. In total, 32S implants were inserted in 132 previously grafted sinuses. Of those, 24 implants were reexamined after a minimum of 6 months of being anchored subgingivally. The osseointegration was verified clinically by the absence of mobility and pain and radiographically by the absence of peri-implant lucency on the retroalveolar and panoramic radiographs.



Results

Implants

Of the 249 implants that were examined after 6 months or more of anchorage, the overall retention rate was 94.8%. Five implants failed to osseointegrate. One had been placed in a very heterogeneous zone of the sinus, quite likely consisting of more fibrous tissue than osseous tissue. There was an infection 6 weeks after the placement of an implant in one patient. The implant was not removed because it was stable (clinically and radiographically integrated) at the time of drainage of the abscess, but it ultimately became mobile and was removed. Eight implants were lost after direct implant loading. Six had been placed in patients presenting with extremely severe bruxism. In spite of these complications, the prosthetic rehabilitation was achieved according to the planned initial treatment.

Marginal bone loss

The radiographic controls done every 12 months (panoramic and retroalveolar) have shown no osteolysis of the peri-implant bone at the emergence of the implants.

Stability of the sinus bone graft

The bone mass inserted in the sinus is best evaluated with CT scan cross sections. The CT scan is the examination of choice for evaluating the volume and density of the bone grafts because of its precision, its relative innocuous properties, and the possibility of sagittal or coronal reconstructions. The control CT scans of seven patients having undergone calvarial bone grafts have revealed, after an initial phase of remodeling of the grafts in the first year postoperatively, perfect stability of the reconstructed zones more than 5 years postoperatively (mean follow-up of 4 to 6 years).

Complications

Besides the absence or the loss of osseointegration of a few implants, four patients presented with an infection occurring early (less than 2 months postoperatively) in the healing process. One patient had a sinusitis that evolved subclinically. It was eventually diagnosed at the control CT scan, 6 months postoperatively. The cranial bone grafts were removed, and the patient underwent regrafting with iliac cancellous bone.

One patient had a vestibular abscess at 6 weeks postoperatively. It was treated by drainage and curet

tage under general anesthesia. Healing was uneventful afterward.

Another vestibular abscess was diagnosed 6 weeks after the insertion of three implants in a previously grafted sinus. Complete healing was obtained after drainage and curettage of a focus of vestibular osteitis. One of the three implants was secondarily lost.

Finally, the third patient presenting with a vestibular abscess underwent drainage under local anesthesia 4 weeks after the graft (see Fig 9-11d). The healing was successful afterward even in the presence of osteosynthesis material. A control CT scan at 6 months showed an excellent reconstruction (see Figs 9-11e and 9-11f).

No complications (seroma, hematoma, infection, or dural tear) were encountered at the donor site, and few patients complained of scalp depression or skull irregularities. In general, there was no relationship between the tearing of the sinus mucosa and the occurrence of an infectious event.

Discussion

Reasons for the use of calvarial grafts

Autogenous bone is undoubtedly the safest and most reliable material in reconstructive skeletal surgery. Among the different donor sites currently used in facial surgery, the cranial vault has been preferred by Tessier⁴ since the beginning of the 1980s. This choice was dictated by the simplicity and the near lack of discomfort in the postoperative period, and, more importantly, by the quality of the construction: high density and low resorption, resulting in long-term stability (Figs 9-11a to 9-11i). In my opinion and that of Tessier, these are the characteristics of the reconstructions done with cranial bone grafts, and, more generally, the predominantly cortical grafts.

The same clinical and radiographic observations have been made by others, particularly those involved in craniomaxillofacial surgery. They have led to experimental studies that confirmed that calvarial bone grafts are superior to iliac grafts in craniofacial reconstruction because of an increased retention of the graft⁹ and a greater than twofold radiographic density.¹¹ More generally, it has been demonstrated that membranous bone undergoes less resorption than endochondral bone.^{12,13}

Although these differences correlate with the embryonic origin, the reason for increased retention of calvarial graft remains unclear. It has been suggested that because of early revascularization of the membranous bone (calvarial graft), as demonstrated by Zins and Whitaker¹³ and then by Kusiak et al/⁴ a greater percentage of the graft is preserved as living bone. However,

Figs 9-11 a and 9-11 b Patient missing the right second premolar and molars with atrophy of the alveolar ridge.

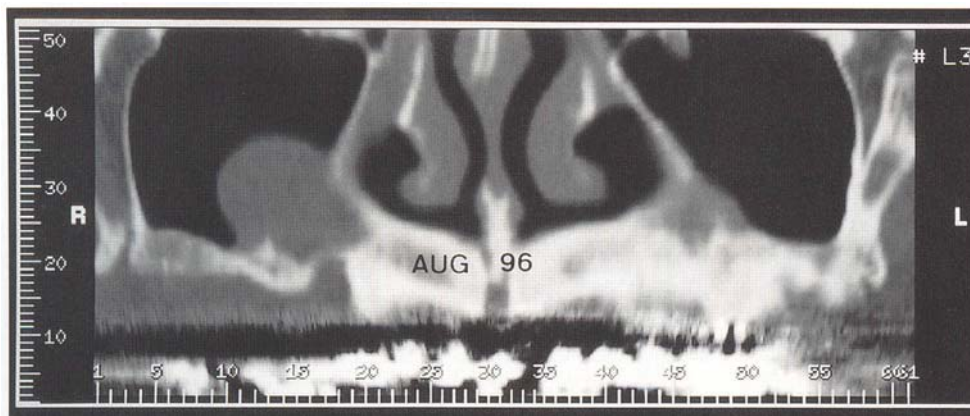


Fig 9-11a Panoscan.

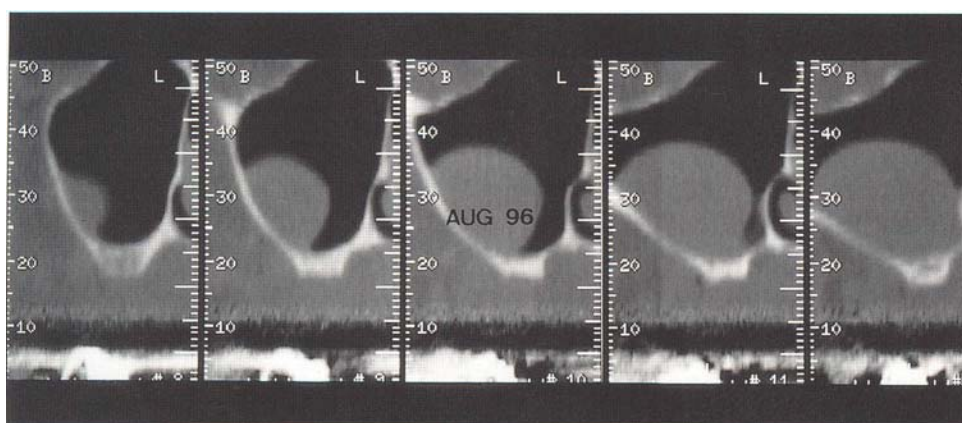


Fig 9-11b Dentascans.

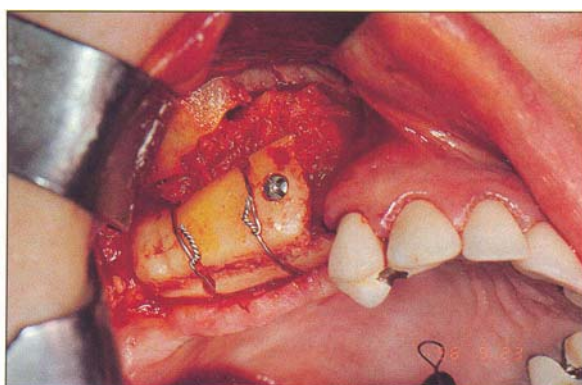


Fig 9-11 c Sinus graft and reconstruction of the alveolar ridge according to the procedure described in Fig 9-10. •

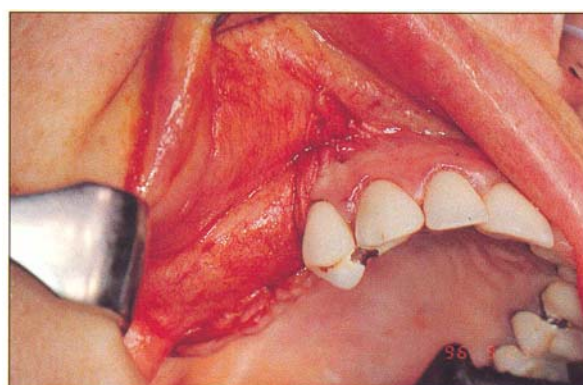


Fig 9-11 d Conditions at the end of the surgery after closure of the vestibular flap. An abscess was diagnosed 4 weeks later and was treated by drainage under local anesthesia and antibiotic. Resolution of the infectious event was rapid.

Figs 9-11e and 9-11f Appearance 7 months after surgery (and 6 months postdrainage of the vestibular abscess). The endosinusual cyst has progressed but without signs of sinusitis clinically and endoscopically. The sinus mucosa was normal.

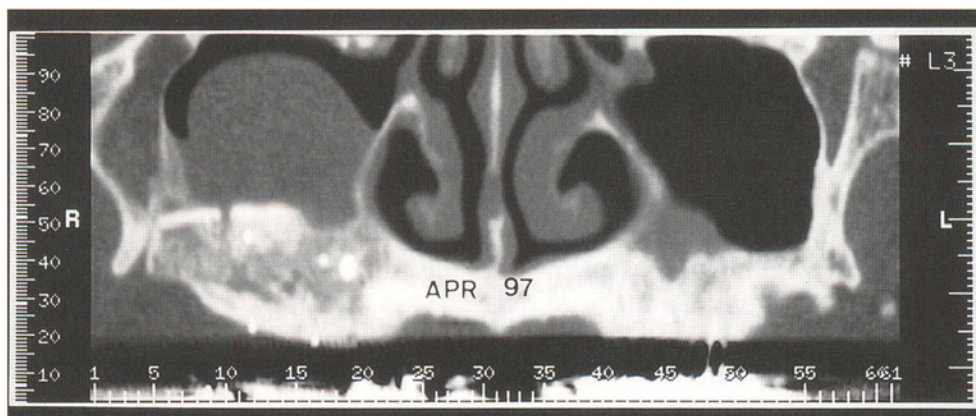


Fig 9-11e Panoscan.

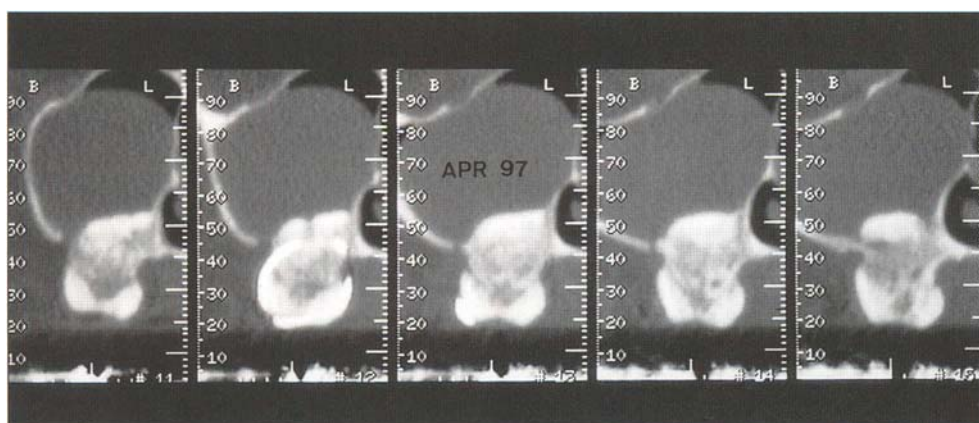


Fig 9-11f Dentascan.

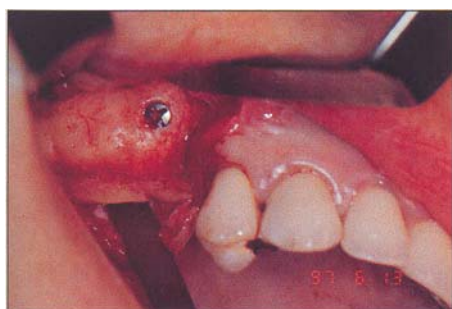


Fig 9-11g Exposure of the reconstructed zone, revealing no resorption of the grafts (at 7 months).



Figs 9-11h and 9-11i Placement of three Brånemark implants, 10 mm in length, in the positions of the second premolar, first molar, and second molar.

experimental studies¹⁵ have conversely demonstrated that revascularization of cancellous bone, particularly the iliac graft,¹⁶ is greater and more rapid than that of the cranial graft.

Hardesty and Marshlo hypothesized that the differences observed in graft resorption and incorporation were directly related to the three-dimensional osseous architecture of the graft. With earlier vascular penetration made possible in the rather loose, abundant cancellous portion of iliac bone, as compared to the dense

and relatively thin diploic space of calvarium, osteoclastic resorption would be more pronounced, thereby allowing inward collapse of the iliac cortical plate. This architectural explanation was reinforced by the experimental studies of Sullivan and Szwajkun,¹⁶ which showed that cortical bone does appear to be a barrier to vessel ingrowth. Moreover, the relatively thin cortical plate of the iliac graft is probably more susceptible to resorption prior to appositional bone formation than the more robust calvarial graft.¹⁰

To summarize, calvarial bone is considered better able to retain its volume because it is predominantly cortical. Nevertheless, as suggested by Hardesty and Marsh,¹⁰ it must be remembered that "current concepts of bone graft survival are largely based on clinical observations and extrapolations from non-primate animal experimentation....."

Development of the surgical procedures

The anchoring of implants in a bone graft does not depend solely on the type of bone used for the graft. It also depends on the homogeneity of the construction. As mentioned, the cranial vault cannot provide large osseous blocks but only fine shavings or corticocancellous strips (plates) cut to the desired dimensions. The thickness of these strips rarely exceeds more than 3 to 4 mm, which is insufficient to reinforce the sinus floor in most patients.

The first 22 patients (1990 to 1991) were treated according to the usual technique described in the literature. This technique of sinus reconstruction consisted of a 90-degree medial rotation of a maxillary bone flap, with a superior-oriented hinge, and simultaneous raising of the mucosa of the floor, followed by the insertion of corticocancellous bone chips underneath the bone flap (on the floor).

The control CT scan done 8 days postgrafting showed, as might have been predicted because of the instability of the "floating" bone flap, a very sparse construction with fragments more or less in contact with each other. At 6 months, the CT scan showed a shrinking of the bone mass, which appeared dense and homogenous. It was not possible to tell if this volume

reduction was due to bone resorption, to a more compact appearance of the fragments, or to both mechanisms. In the long term (5 years or more), the control CT scans of those first patients have always shown a perfect stability of the intrasinus bone mass.

Since January 1992, it was decided to apply the basic principles of bone reconstruction to sinus floor construction: stabilization of the grafts and elimination of dead space. Thus the technique described in this chapter was developed. The procedure consists of partitioning the inferior part of the sinus with a stable graft

and filling it with bone particles that are packed to immediately obtain a homogenous construction.

Osseointegration in calvarial grafts

There are only a few reports of implants inserted in cranial grafts. Donovan et al⁷ reported on 93 Branemark implants placed in 24 patients reconstructed with calvarial bone grafts. Reconstruction was limited to the alveolar ridge and the nasal floor, without opening the sinus. They achieved various success rates (86% to 98%), depending on the type of construction. At the time of implant placement (total of 43 implants in 13 patients), they observed that the reconstruction, done with two-layered, onlay grafts, had shown resorption of the middle layer, which was more or less replaced by soft tissue.¹⁷

Jensen and Sindet-Pedersen¹⁸ reported a 94.5% success rate in severely atrophied maxillary alveolar ridge reconstructed with bone grafts from the mandibular symphysis. In some patients, these cortical grafts, quite similar to calvarial bone, were placed on the sinus floor. Zerbib¹⁹ has reported a low failure rate: twenty-two of 53 implants placed in sinus grafts of iliac or cranial origin were lost.

Similarly, Daelemans (Personal communication, 1997) and Malevez (Personal communication, 1997) have observed excellent integration of implants inserted in sinuses grafted with calvarial or iliac bone. I have observed comparable results with iliac bone graft: The density of the iliac grafts was lower than that of cranial grafts, although there was no significant resorption on the control CT scan at 5 years.

Decisive advantage of calvarial bone grafts

The surgery generally ends with the (more or less) total reconstruction of the alveolar ridge. This is where the cranial bone graft has its utmost justification (see Figs 9I to 9-11i). Indeed, the intrasinus iliac bone seems to retain its initial mass like the cranial bone (the essential difference being in the density), but it does not do so on

the alveolar crest, where a certain degree of resorption of onlay iliac grafts is usual. On the other hand, the bone resorption is nonexistent or minimal with cortical grafts, which can be harvested from the chin or from the cranium, if the chin's bone mass is insufficient.

Cranial bone grafts offer the invaluable advantages of a high-quality reconstruction as well as an extremely low postsurgical morbidity. Indeed, the donor site is usually painless with minimal local reactions, rendering the follow-up as simple as that for an isolated surgery on the maxillary sinus.

All the patients who were treated by Donovan et al¹⁷ and who answered a questionnaire regarding the postoperative period reported not having suffered at the site of the cranial harvesting.

Disadvantages of calvarial bone grafts

The general anesthesia and the weakening of the cranial vault (which protects the brain) can make certain patients hesitant about the procedure. An alternative for these patients is harvesting of the chin symphysis, which can be done under local anesthesia and should be kept as an option when the need for bone is limited. Likewise, patients presenting with advanced baldness will generally prefer a donor site other than the cranium to avoid a visible deformation of the parietal region (though this is usually very moderate) or a visible scar (also typically not apparent).

Although harvesting of bone from the calvarium is not very difficult, it requires special training to avoid major complications such as those described by Cannella and Hopkins²⁰ and Frodel et al²¹. From a multicenter study of more than 13,000 cranial bone graft harvestings, Kline and Wolfe²² identified seven temporary and four permanent neurologic complications, all of which took place (except for three temporary deficits) in patients treated by surgeons having little or no experience in this field.

To avoid exposing, or especially tearing, of the dura, it is important to evaluate the thickness of the cranial vault before proceeding. Pensler and McCarthy²³ measured skull thickness on 200 fresh adult cadavers. The mean value was a little more than 7 mm, with a maximum thickness in the posterior parietal region. Two or three frontal telerradiographs with different views allow a direct measurement of the thickness and the localization of irregularities. If the cranial vault is too thin or made purely of cortical bone (no diploic space), another site of harvesting should be chosen (eg, iliac crest).

Finally, the extremely cortical nature of calvarial bone can compromise the healing of the graft, especially if the volume of the grafts exceeds the "critical

mass" that can be revascularized by the recipient site. This notion of critical mass was initially recognized by Tessier⁴ after he observed cases of sequestration of the central part of bone grafts. From his vast experience, Tessier (Personal communication) thinks that no part of a graft should be more than approximately 10 mm from either the recipient bone surface or the periosteal sheath. It is likely that the complications observed in two of the patients in the present study were related to excessively large bone grafts. Since then, particular attention has been given to the critical bone mass for each patient, and this complication has been totally avoided. However, the specific amount of bone to be grafted is determined mainly by the local and anatomic conditions of the patient and by the experience of the surgeon.

Reasons for a two-stage approach

The risk of losing not only the implants but also the grafts in the event of an infection is a sufficient reason to assess the quality of the reconstruction clinically and radiographically before the placement of the implants. Moreover, it is impossible to consider the simultaneous placement of implants at the time of grafting because, as previously stated, osseous blocks cannot be harvested from the calvarium, and stability cannot be expected in a mass of bone chips. This approach could be feasible if there were sufficient height of the residual alveolar bone (at least 5 mm) to permit a primary stabilization of the implants. In this situation, the implants could not occupy an ideal position in relation to the prosthesis because of the frequently atrophied alveolar bone, more marked on the vestibular side. For these reasons, it is preferable to reconstruct in a first stage, wait a minimum of 6 months for the resorptive phenomena to have stabilized, and then place the implants if the anatomic conditions are favorable.

Conclusion

The reconstruction of the lateral sectors of the maxilla by grafting of the floor of the sinus with calvarial bone has proven to be a safe and reliable procedure. The major advantages of harvesting the bone from the calvarium are the lack of donor site morbidity, the large amount of available bone, the high density of the grafted area, the absence of or very low bone resorption of the grafts when placed on the alveolar crest, and the short hospitalization. However, this type of harvesting is reserved for the experienced surgeon who has received the appropriate training and is working as a team with a neurosurgeon.

Acknowledgments

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Autogenous Free Bone Graft Harvesting for Sinus Floor and Alveolar Reconstruction

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Obtaining free bone-grafting material for augmentation of the sinus floor and the alveolus requires not only a mechanical approach but a biologic one as well. The use of cortical bone, cancellous bone, or a combination of both depends on the type of osseous deficiency present. Small grafts are usually obtained from maxillofacial sources. When the defect is larger and the site is compromised in its regenerative capacity, a tibial graft can be used. Larger grafting requirements are best served by using the iliac crest from either an anterior or a posterior approach. Total alveolar, sinus, and Le Fort combination grafting is best served by using the posterior ilium. It is unusual for these harvesting sites not to supply sufficient bone to manage typical alveolar or jaw discontinuity defects.

Intraoral Donor Sites for Sinus Grafting

Although the harvesting of bone is associated with a low morbidity, the ramus donor site is subject to fewer complications. Implants are placed secondarily following a 4- to 6-month healing period. Onlay grafts exhibit minimal resorption and maintain their dense quality.

Graft morphology

Mandibular bone grafts have been used for alveolar repair to allow implant placement with extremely favor

able results.¹⁻¹⁵ Block-type grafts may be harvested from the mandibular symphysis, body, or ramus area. However, the anatomy of these regions results in different graft morphologies. Symphysis grafts are larger in overall volume and have a corticocancellous morphology. The ramus area provides a mostly cortical graft that is well suited for veneering ridge deficiencies. However, in some cases, it is more difficult to obtain surgical access to the ramus than to the anterior mandible.

A comparison of graft size revealed that the overall volume from the symphysis is approximately 50% greater, mainly because of the increased thickness of the grafts. The average interforaminal distance is approximately 5 cm, so localized bone deficiencies requiring a larger graft may be better managed with the symphysis as a donor site.¹⁶ Cases 1 and 2 demonstrate conditions for which onlay grafting is necessary in addition to sinus grafting (Figs 10-1a to 10-1c; 10-2a and 10-2b). The dimensions of the mandibular symphysis allow the harvest of a sizable block and additional particulate graft. Although no postoperative alteration in soft tissue chin contour has been reported with symphysis grafts,^{5,8,9,11,14,17,18} patients are concerned with the possible esthetic consequences of bone removal from this area. Radiographic evidence of incomplete bony regeneration has been reported in elderly patients.³ However, the reported incomplete bone fill did not result in any discernible profile changes. No postoperative alteration in chin contour has been observed clinically or radiographically after grafting of the donor area with a resorbable hydroxyapatite material. Ptosis of the chin has not occurred and can be prevented by avoiding degloving of the mandible.¹⁹

The limits of the ramus area are more often dictated by clinical access in addition to the locations of the coronoid process, molar teeth, and inferior alveolar canal. A rectangular piece of bone of up to 4.0 mm in thickness may be harvested from the ramus. This morphology conforms especially well as a veneer graft to gain additional ridge width. The length of the rectangular graft may approach 3.5 cm, but the height usually is not much greater than 1.0 cm. Patients have shown less concern with bone removal from the ramus area. Because the masseter muscle provides soft tissue bulk, augmentation of this donor site has been unnecessary.

The morphology of the ramus block graft is more often cortical, whereas the symphysis is more corticocancellous. In addition, the symphysis donor site allows the procurement of some additional cancellous bone after the block is removed (Figs 10-1d and 10-1e; 10-2e and 10-2f). Ronguers or chisels may be used to remove the cancellous bone. A small-diameter trephine bur (3 to 5 mm) can be used to harvest bone cores lateral to the block site for use in grafting the sinus floor. This particulate bone can be used to augment other areas or fill discrepancies between the block graft and host bone. However, as described by Buhr and Coulon,¹⁶ the volume of obtainable cancellous bone in the symphyseal area is meager.

Depending on sinus dimensions, enough bone can often be harvested from the symphysis to graft one sinus. If additional graft volume is needed, alloplastic and/or allogeneic graft materials may be placed first to gain height. The autogenous particulate graft is then placed onto the sinus floor (Figs 10-1f and 10-1g; 10-2d, 10-2g, 10-2h, 10-2i).

Postoperative complications

The ramus donor site is associated with fewer postoperative complications. Incision dehiscence occurred in three of 28 patients with a vestibular approach to the anterior mandible. Two of these patients also developed infections of the grafted donor site that resolved uneventfully following antibiotic therapy. No incision line dehiscence was found at the posterior donor site or in cases where a sulcular incision was made to access the symphysis. A vestibular approach with an incision well beyond the mucogingival junction creates easier access but produces more soft tissue bleeding and intraoral scar formation. Patients with a ramus graft appeared to have fewer difficulties with managing postoperative edema and pain.²⁰

Patients were less able to discern neurosensory disturbances in the posterior buccal soft tissues than in the lower lip. Although the incision along the external oblique ridge could possibly damage the buccal nerve,

reports of postoperative sensory loss in the buccal mucosa are rare, and such changes would most likely go unnoticed by the patients.²¹ The incidence of temporary mental nerve paresthesia for symphysis graft patients was approximately 10% (3/31), and postoperative neuropraxia was not uncommon. Eventually all patients demonstrated recovery.

The potential for damage to the inferior alveolar nerve, as opposed to its peripheral mental branches, is of greater concern with the ramus graft technique. The surgery has many features similar to sagittal split ramus osteotomy.²² Although the buccolingual position of the mandibular canal is variable, the distance from the canal to the medial aspect of the buccal cortical plate (medullary bone thickness) was found to be greatest at the distal half of the first molar (mean of 4.05 mm).³⁰ Therefore, when large grafts are planned, the anterior vertical bone cut should be made in this area. This cut is progressively deepened until bleeding from the underlying cancellous bone is visible. Damage to the neurovascular bundle may also occur during sectioning of the graft. The cut should parallel the lateral surface of the ramus when the thin chisel is used along the external oblique osteotomy.

Altered sensation of the lower anterior teeth was a relatively common postoperative symptom of the patient with a symphysis graft. Almost one third (9/31) of these patients described a dullness in sensation of the incisors; this feeling resolved within 6 months. In contrast, none of the ramus graft patients noted changes in their molar teeth. Although it has been recommended that a 5.0-mm border be left below the apices of the anterior tooth roots when bone is harvested from the chin,³² the contents of the incisive canal, which innervate the teeth, may still be disturbed. However, unless clinical signs of pulpal necrosis become apparent (discoloration or radiographic change), endodontic therapy is not indicated.³³ Although the need for endodontic therapy has not arisen and the risk of damage to the teeth is minimal, patients should be aware of the potential for pathologic changes.

Postoperative healing

The grafts were allowed to heal for only 4 months for maxillary recipient sites and 5 to 6 months for mandibular sites (Figs 10-1h and 10-2j). Although a 6 to 9-month healing period has been recommended for bone grafts of endochondral origin,⁴ a 4-month healing period has been shown to be sufficient for mandibular bone grafts.^{s,B} The recommendation for a shorter healing time was based on the hypothesis that membranous bone grafts revascularize earlier than endochondral grafts.^{3s,36}

Case 1

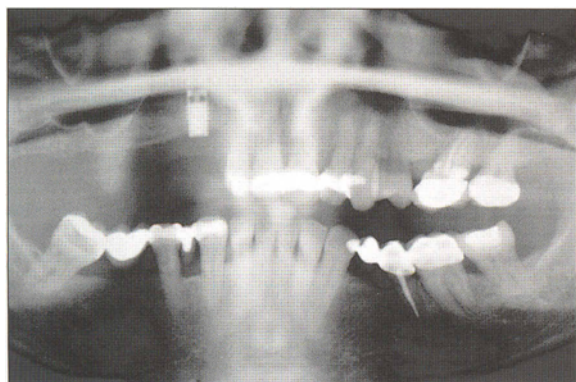


Fig 10-1a The panoramic radiograph reveals a non-storable hollow-basket implant in the maxillary right posterior area and a pneumatized sinus. The patient had a failed cantilevered implant prosthesis.

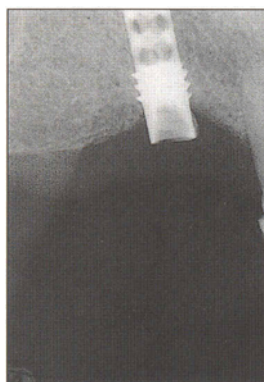


Fig 10-1b Periapical radiograph of the non-restorable hollow-basket implant.



Fig 10-1c The non-storable hollow-basket implant has been removed. Note the unfavorable residual ridge relationship to the mandibular arch.

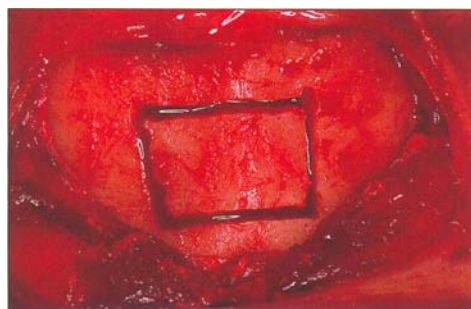


Fig 10-1d The block corticocancellous bone graft from the mandibular symphysis is outlined.

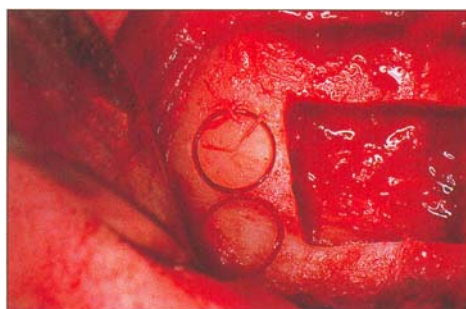


Fig 10-1e A trephine bur is used to harvest bone cores from the mandibular symphysis. Cancellous bone is also procured from the donor site following removal of the bone block.



Fig 10-1f The cancellous bone graft is placed on the sinus floor following placement of the corticocancellous bone cores. The block graft is fixed to the ridge defect anteriorly.



Fig 10-1g The cancellous graft is firmly packed over the lateral opening and around the block graft.

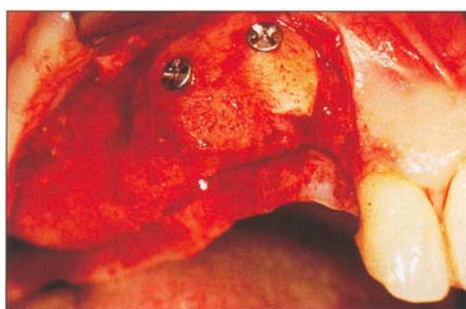


Fig 10-1h The reconstructed maxilla is exposed 4 months after placement of the autograft.

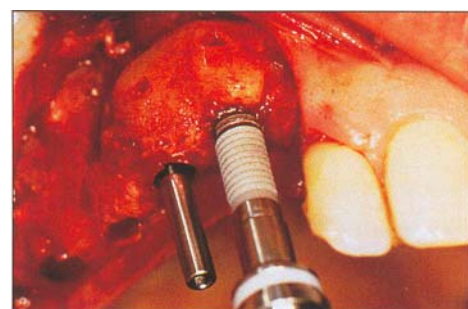


Fig 10-1i Four titanium plasma-sprayed implants are placed in the grafted maxilla.

The quality of the healed bone graft upon incorporation is usually denser than the typical maxilla when mandibular bone grafts are used.²⁰ Implants are placed secondarily after graft healing (Figs 1a-1i; 10-2k and 10-2l). The implant healing time is designated by the quality of the sinus graft. The implants are uncovered and a provisional prosthesis is fabricated to progressively load the implants prior to delivery of the final implant prosthesis (Figs 10-1j to 10-1l; 1a-2m to 10-2p).

Summary

Autogenous bone grafts harvested from the mandible offer several advantages in the reconstruction of alveolar ridges for implant placement. These grafts require a short healing period and exhibit minimal resorption while maintaining their dense quality. The ramus area has some advantages over the mandibular symphysis as a donor site (Table 10-1). They include minimal patient

concern for altered facial contour, lower incidence of incision dehiscence, decreased complaints of postoperative sensory disturbances, and proximity to posterior mandible recipient sites. However, surgical access is

more difficult to obtain in some patients, and there are limitations to the size and shape of the graft. The symphysis offers the potential for thicker grafts with a greater cancellous component.



Fig 10-lj Frontal view of the restored maxillary arch.

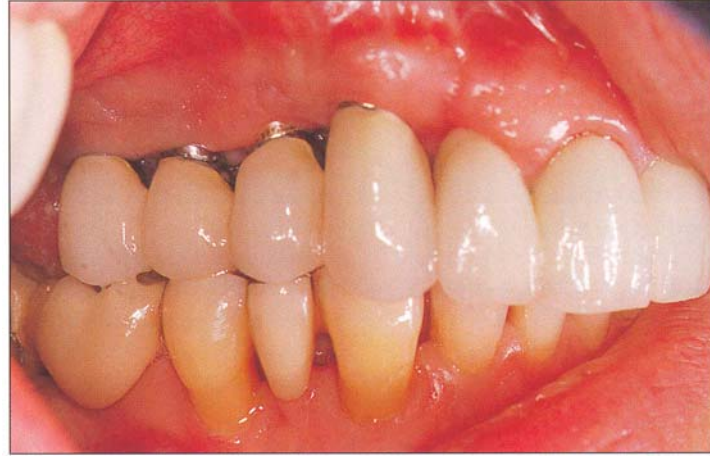


Fig 10-lk Lateral view of the fixed implant-supported splinted crowns.

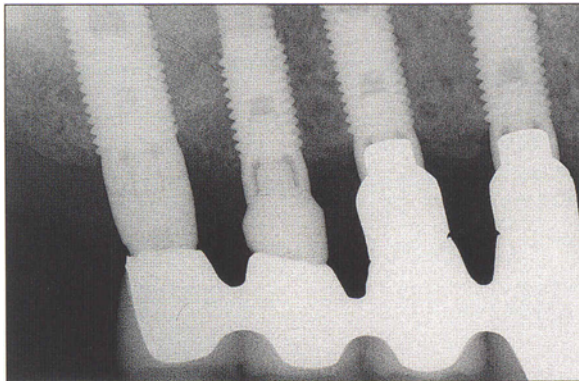


Fig 10-1\ Periapical radiograph of the restored maxillary implants taken at a follow-up maintenance visit.

Table 10-1 Comparison of mandibular donor sites

Parameter	Symphysis	Ramus
Surgical access	Good	Fair to good
Cosmetic concerns	High	Low
Graft shape	Thick rectangular block	Thinner rectangular veneer
Graft morphology	Corticocancellous	Cortical
Graft size	>1cm ³	<1 cm ³
Graft resorption	Minimal	Minimal
Healed bone quality	Type 2 > type 1	Type 1 > type 2
Donor site complications		
Postoperative pain/edema	Moderate	Minimal to moderate
-Neurosensory changes-teeth	Common (temporary)	Uncommon
Neurosensory changes-tissue	Common (temporary)	Uncommon
Incision dehiscence	Occasional (vestibular)	Uncommon

Case 2

Fig 10-2a The periapical radiograph reveals advanced bone loss around the maxillary posterior teeth.

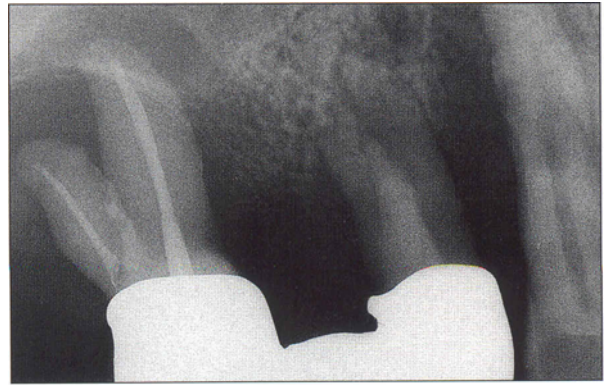


Fig 10-2b The maxillary right posterior teeth have been extracted. Note the unfavorable residual ridge relationship to the mandibular arch.

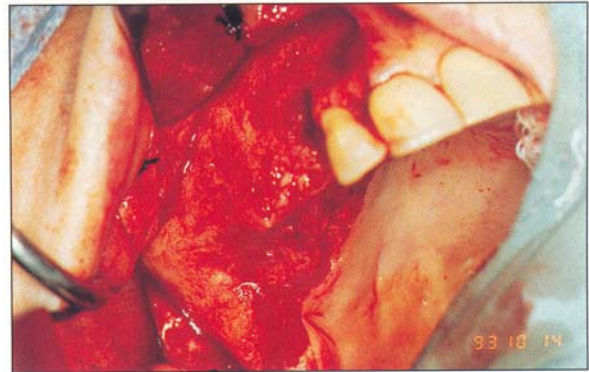


Fig 10-2c The posterior maxilla is exposed in preparation for sinus grafting.

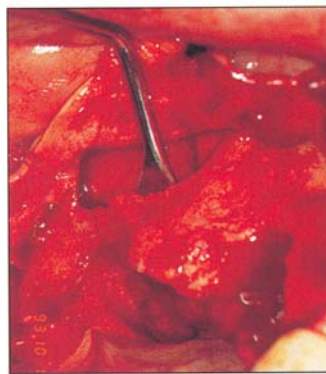


Fig 10-2d The sinus mucosa is elevated with curette following infraorbital incision of the lateral maxillary bony window.



Fig 10-2e The mandibular symphysis donor site is exposed.

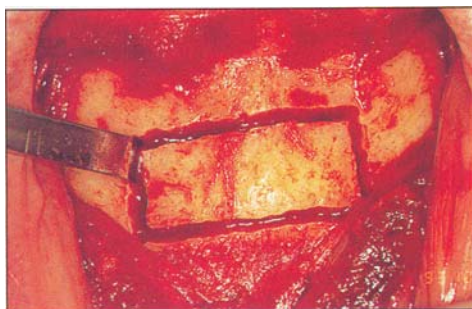


Fig 10-2f The block corticocancellous bone graft from the mandibular symphysis is outlined.

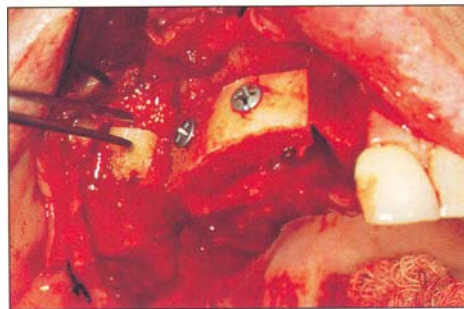


Fig 10-2g Bone cores harvested from the mandibular symphysis are placed on the sinus floor following an initial layer of xenograft.

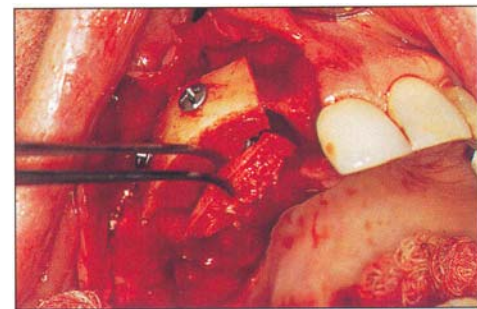


Fig 10-2h Additional cancellous bone harvested from the tuberosity is placed around the fixed block graft.

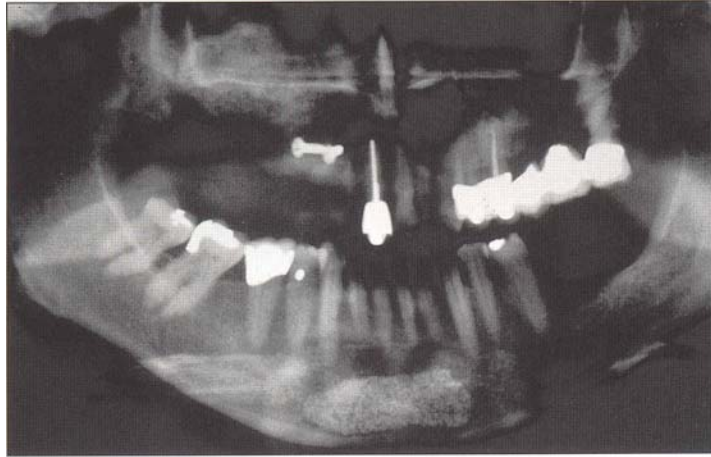


Fig 10-2i Postoperative panoramic radiograph of the sinus graft and fixed block graft.

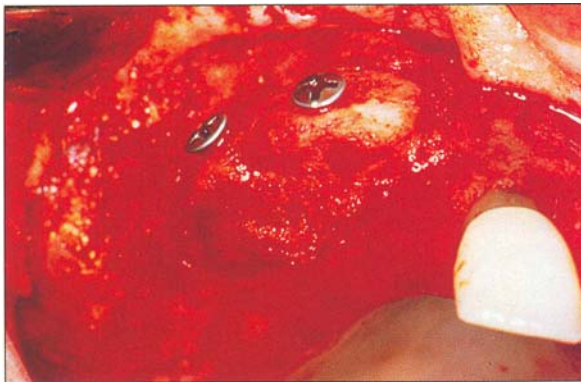


Fig 10-2j The grafted maxilla is exposed for implant placement. Note the excellent incorporation of the graft.

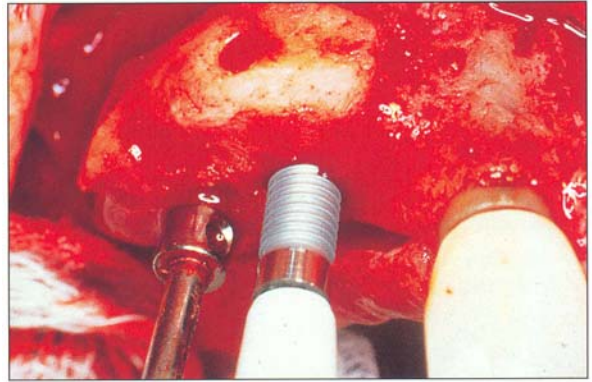


Fig 10-2k Titanium screw-type implants are placed in the grafted maxilla.

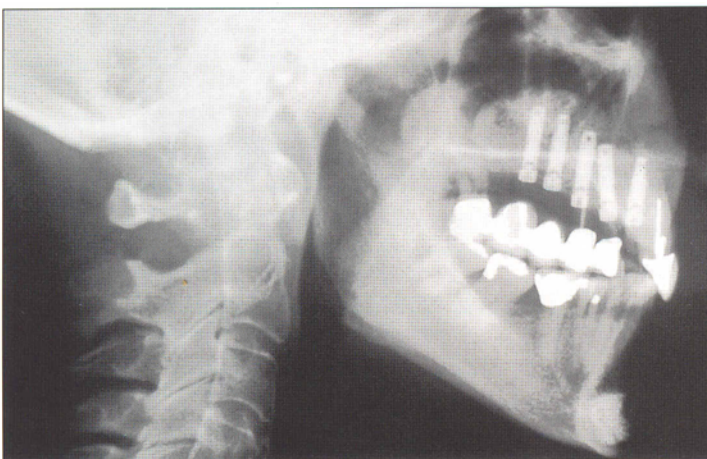


Fig 10-2l The lateral cephalometric radiograph reveals the implants placed in the grafted maxilla and the mandibular symphysis donor site grafted with resorbable hydroxyapatite.

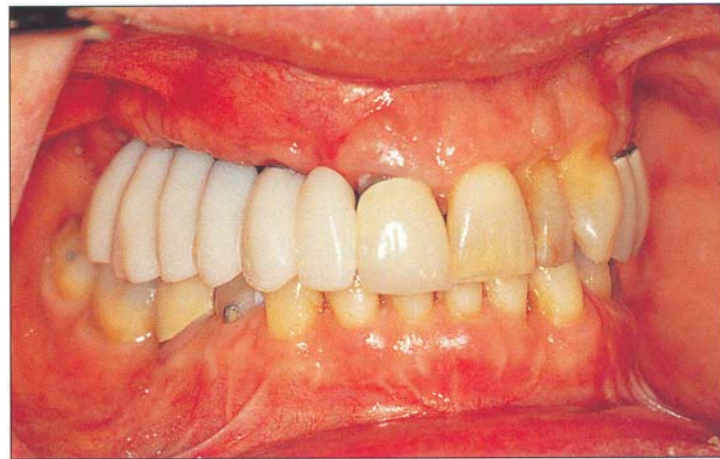


Fig 10-2m The maxillary implants are progressively loaded with an acrylic resin provisional prosthesis.

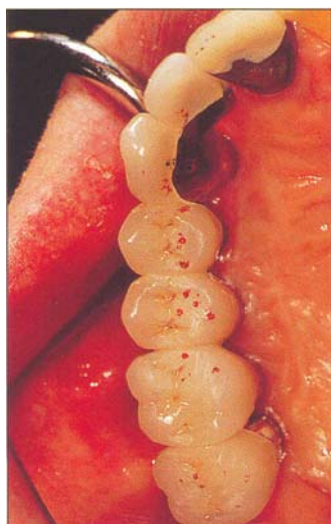


Fig 10-2n Occlusal view of the implant-supported, cement-retained, porcelain-fused-to-metal fixed prosthesis.

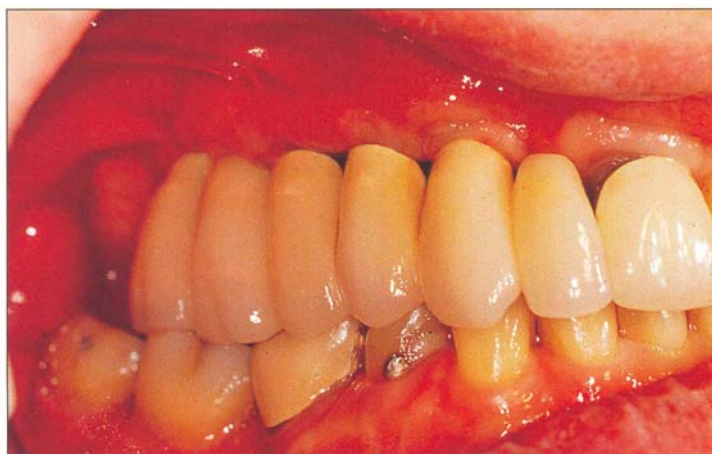


Fig 10-20 Lateral view of the implant-supported fixed prosthesis.

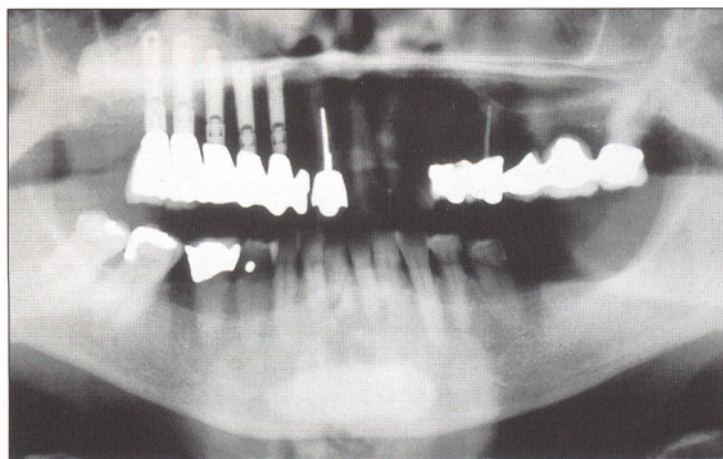


Fig 10-2p Panoramic radiograph of the restored maxillary implants.

Tibial Cancellous Autograft for Sinus Grafting

Various donor sites and bone-harvesting techniques are used for the augmentation of the sinus floor prior to the placement of osseointegrated implants, but seldom has the proximal lateral tibial graft been utilized, despite its excellent accessibility and availability.^{37,38} When the bone volume or bone quality is extremely deficient, such as in the class D case (Fig 10-3), the tibial graft is recommended.

The proximal lateral tibial graft has a number of convenient advantages over other donor sites and techniques:

1. Up to 40 cm³ of cancellous bone can be harvested from the lateral aspect of the proximal tibia.^{37,39}
2. It is a simple procedure that can be done using general anesthesia or in-office conscious sedation.^{37,39,40}
3. The total procedure time averages only 20 minutes.³⁹
4. Blood loss is minimal, and neither a bloodless field nor drainage is required.^{37,39}
5. Patients report minimal pain and dysfunction.³⁷
6. The procedure allows immediate weight bearing postoperatively.^{37,39}
7. Studies show complications and morbidity to be relatively lower than with other techniques, such as the iliac crest graft.^{37,39,40} The incidence of complications of tibial grafts is reported to range from 1.3 % to 3.8%, which compares favorably with that of iliac crest harvesting, 8.6 % to 9.2 %.^{38,39,41}
8. Studies reveal that postoperative bruising is minimal, healing is generally uneventful, and postoperative scarring is unremarkable.³⁹

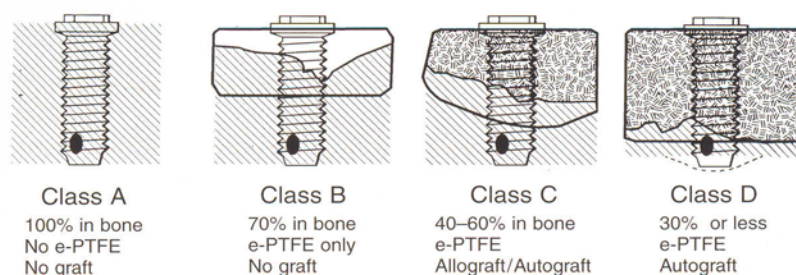


Fig 10-3 The autogenous tibial graft is recommended for the highly deficient bone morphology that is compromised by insufficient bone volume or poor bone quality (class D).

Surgical preparation and anatomy

The patient is placed in a supine position. A roll may be placed under the ipsilateral hip to elevate the anterolateral tibia.³⁷ The donor site is prepared in the usual fashion with iodine or a povidone-iodine solution and appropriate sterile draping.

The tibial condyles should be palpated immediately below the knee. On the anterior surface of the proximal end of the tibia, between the condyles, is an oval protuberance called the *tibial tuberosity* or *Gerdy's tubercle*⁴² (Fig 10A). The tubercle should be located and palpated. Properly locating Gerdy's tubercle prior to the incision is essential to avoiding violation of the articular surface of the tibial plateau and damage to the articulation of the knee. In addition, maintaining this anatomic position prevents involvement of the head of the fibula, which is also located subcutaneously at this level.^{1,37,42}

A 2- to 3-cm oblique incision is made directly over Gerdy's tubercle with a No.10 scalpel.^{1,37,40} The incision should be angled with its cephalad limit just above and medial to the origin of the tibialis anterior muscle and its caudal extent lateral to the patellar ligament.³⁷ The incision is made through skin, subcutaneous tissue, and fascia of the iliotibial tract of the fascia lata and through periosteum.^{37,40}

The small blood vessels in the immediate vicinity of the lateral proximal tibia include branches of the medial superior and inferior genicular arteries which pass under cover of the patellar ligament; branches of the lateral inferior genicular, fibular, and the anterior recurrent tibial; and branches of the anterior tibial artery.

The two vessels at most risk in the immediate surgical area are the anterior tibial recurrent and lateral inferior genicular arteries.^{37,39,40,42} Injury to these vessels will be avoided by appropriate placement of the incision.^{37,39,40} Bleeding from these vessels is minimal and can easily be controlled with diathermy.³⁷

The primary muscle in this surgical area is the anterior tibial muscle, located on the lateral surface of the tibia. Its fibers course vertically, overlapping the anterior tibial vessels and the deep peroneal nerve in the proximal tibial region. This nerve arises from the bifurcation of the common peroneal nerve between the fibula and the peroneus longus muscle. The peroneal nerve then continues deep to the extensor digitorum longus muscle and on to the anterior surface of the interosseous membrane.^{37,42} Injury to this nerve is also avoided by the proper placement of the initial incision.³⁷

Graft procurement

Following sterile preparation (Fig 10-Sa) a 2- to 3-cm mini-incision is made over Gerdy's tubercle. A surgical handpiece and straight fissure bur are utilized to remove a 1- x 2-cm portion of cortical bone. Curved or straight orthopedic curettes are then used to harvest the desired quantity of cancellous bone^{37,40} (Fig 1 O-Sb). Generally up to 40 cm³ of cancellous bone can be procured per tibia.^{37,39} The use of hand instruments whenever possible is recommended, because power-driven instruments will increase the likelihood of thermal injury to the bone graft.⁴⁰

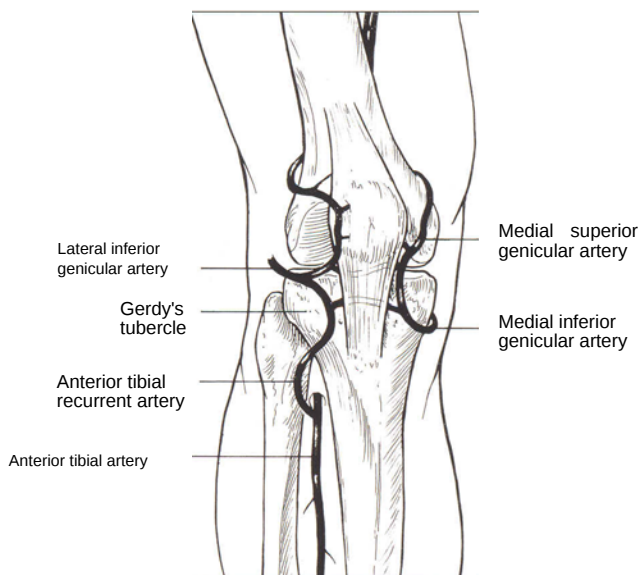


Fig 10-4 At the anterior proximal surface of the tibia, Gerdy's tubercle is readily palpable. A 2-cm incision made directly over the tubercle provides access to the harvesting site and provides an anatomic location that will ensure that the tibial plateau will not be violated.



Fig 10-5a A tibial graft site is prepared and draped in a sterile manner.

Fig 10-5b A large volume of tibial marrow bone is retrieved. About 20 cm³ of bone is retrieved in this case.



Graft handling

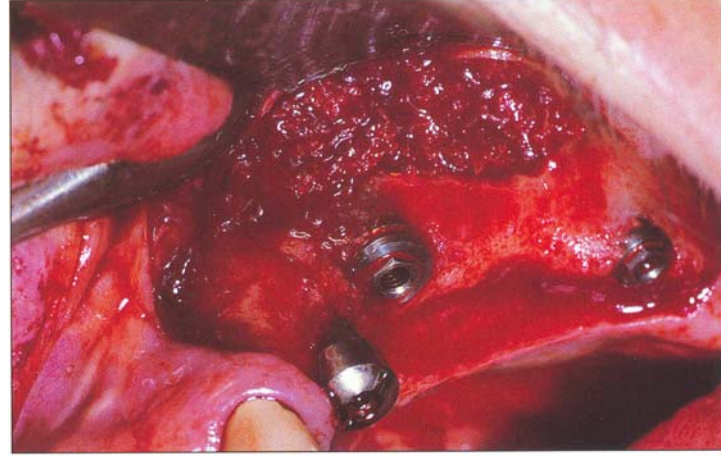
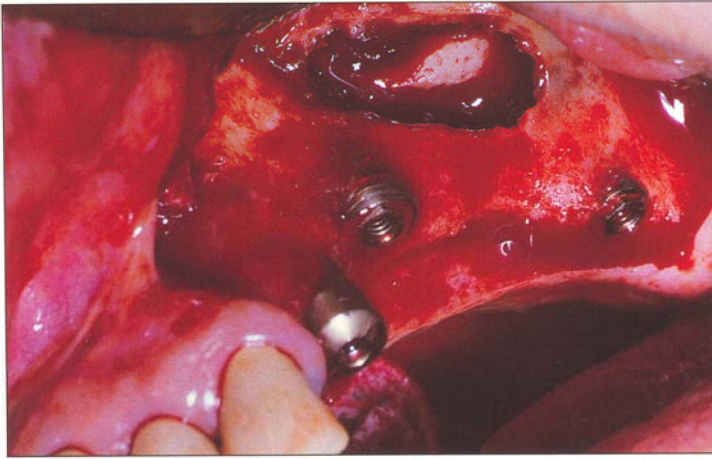
The method of storage and handling of the graft from the period of harvest to implantation can considerably alter its viability.⁴³ Research has indicated that storage of a graft exposed to air for less than 3 hours has no effect on osteogenesis.⁴⁰ However, others maintain that exposure to air for as little as 20 minutes reduces the viability of the graft.^{40,44-46} Storage in saline or antibiotic solution is deleterious, and direct application of antibiotic powders has the most harmful effects.^{40,43,47} In general, it is recommended that the graft, once harvested, be immediately transplanted.^{40,44}

Figures 10-5c to 10-5f demonstrate immediate implant placement in bilateral sinus graft where class C/D sinus morphology is present. The implants are placed first, and then cancellous bone is compacted around the implants.

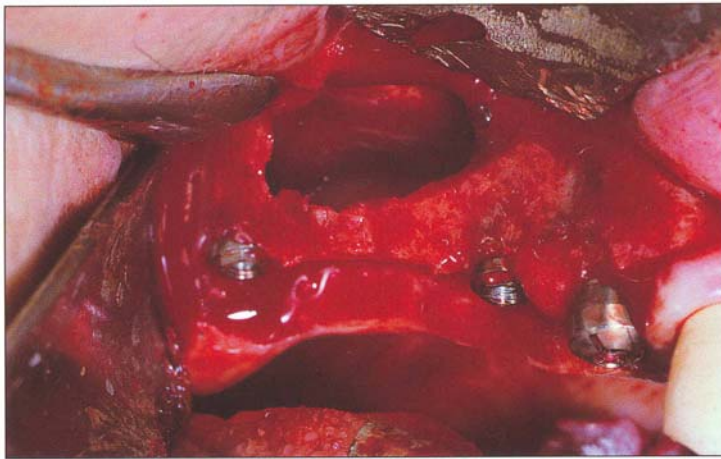
Postoperative wound management

No attempt is made to fill the metaphyseal dead space with an alloplastic material.^{1,37,39} The wound is not drained and can be closed in layers in the usual fashion^{37,39} (Fig 10-5g). The periosteum may be approximated with 3-0 Vicryl and the skin with 4-0 Ethylon sutures.³⁹ A continuous subcuticular suture may be used for better esthetic results.³⁷ Wound closure is followed by application of an antibacterial ointment and a nonstick dressing.³⁷ A small pressure bandage is then applied for 24 hours.³⁹ This may be accomplished by first wrapping the donor site with a Kerlex bandage (Johnson & Johnson) and then wrapping the knee and leg with an Ace bandage (Conco).³⁷

Postoperative ambulation is begun the same day or the following morning, and sutures can be removed after 7 days.^{37,39,40} All patients should receive an intravenous or oral course of antibiotics to cover the donor site procedure, if antibiotics were not previously administered to cover the primary surgical procedure.³⁷



Figs 10-5c and 10-5d The right sinus is grafted after implant placement.



Figs 10-5e and 10-5f The left sinus is grafted after implant placement.

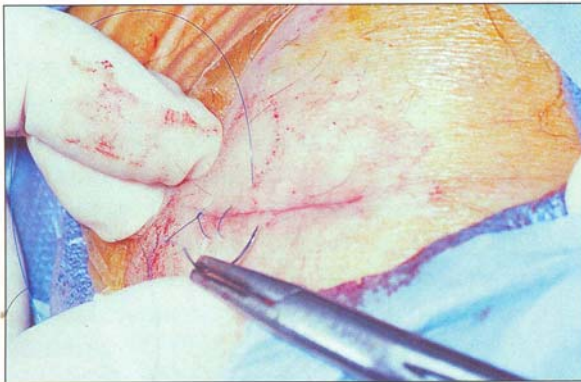


Fig 10-5g The tibial graft site is closed primarily, and a compression dressing is placed.

Conclusion

The lateral proximal tibial metaphysis offers a promising alternative source of moderate amounts of cancellous bone with a minimum of morbidity.^{37,39,40} Harvesting bone from the lateral proximal tibia is simple when the surgeon is familiar with the anatomy of the lower extremity.⁴⁰ Keeping the graft in a blood-soaked sponge and minimizing the period from explanation to

implantation are key components of maintaining the viability of the bone graft.^{40,43,44,48} The procedure has the added advantage of being a relatively quick procedure that can be done in the office with the patient under conscious sedation. Overall, the low complication rate, minimal patient discomfort, minor bruising, and limited postoperative scarring makes the lateral proximal tibia a very practical and viable bone source for sinus-grafting procedures.

Simultaneous Placement of Hydroxyapatite-Coated Implants and Autogenous Bone Grafts

Michael S. Block, DMD
John N. Kent, DDS

Bone availability is the key to successful placement of endosseous implants in the posterior maxilla. When the thickness of the bone between the sinus and alveolar crest is less than 10 mm, increasing the thickness of the alveolus sinus floor through grafting is necessary to support the required long implants and prosthetic restoration. The grafting material chosen must provide adequate viable bone to stabilize the implant and encourage osseointegration. Criteria for an ideal graft include!:

1. The ability to produce bone by cellular proliferation from viable transplanted osteoblasts or by osteoconduction of cells along the graft's surface.
2. The ability to produce bone by osteoinduction of recruited mesenchymal cells.
3. Remodeling of the initially formed bone into mature lamellar bone.
4. Maintenance of the mature bone over time without loss through function.
5. The ability to stabilize implants when placed simultaneously with the graft.
6. Low risk of infection.
7. Ease of availability.
8. Low antigenicity.
9. A high level of reliability.

Autogenous bone best fulfills these criteria.

Various authors reference Tatum as first performing sinus augmentations in the mid-to-late 1970s.²⁻⁴ Boyne and James were the first to report their 4-year experiences with autogenous bone placed in the sinus; the graft was allowed to heal for 6 months before place

ment of blade implants. Tatum,⁶ in 1986, reported his techniques for raising the sinus membrane from a lateral approach as well as raising the membrane from an inferior approach through the implant preparation site.

Case reports by Wood and Moore⁷ in 1988 demonstrated the potential for using ramus or coronoid bone as the graft source. Kent and Block,⁸ in 1989, reported the 4-year follow-up of the use of autogenous hip bone for the grafting material and simultaneous placement of hydroxyapatite-coated implants. To date, bone grafts from the hip (anterior and posterior crests), ramus, coronoid process, tuberosity, chin, calvarium, tibia, and rib have been used.

Reports involving sinus grafting do not include long-term assessment of the amount of bone around the implants.^{2,3,5,6,9-24} We have performed a study utilizing tomography to quantitatively assess the bone level relative to the apical portion of the implant, as well as the height of alveolar ridge, after 5 to 10 years of function.²⁵

Autogenous Bone Grafts

Autogenous bone harvested from the patient is ideal and serves as the standard to which other grafting materials are compared. Autogenous bone grafts, which are primarily cancellous:

- Revascularize quickly.
- Provide phase 1 (immediate) bone production.
- Can be harvested in multiple forms (particles, strips, or blocks).

- Are available from the iliac crest, tuberosity, symphysis, or ramus of the jaws.
- Have no adverse antigenicity because they 'originate from the patient.
- Are extremely reliable.

Disadvantages include donor site morbidity and increased surgical time for harvesting the graft.

Corticocancellous block grafts have an advantage because they maintain structural rigidity and can be shaped to match the host site. Large grafts must be harvested from the anterior or posterior ilium and smaller grafts can be harvested from the symphysis. Traditionally, corticocancellous block grafts were believed to maintain more of their bulk than cancellous grafts when used as onlays.¹ It is unknown whether a cancellous or corticocancellous graft maintains bulk better when placed in the sinus and subjected to implant-transmitted forces.

Healing

The cancellous autogenous bone graft contains endosteal osteoblasts, which can survive the transplantation process when handled appropriately. Also transplanted are a host of growth factors, which provide the stimulus for mesenchymal cell differentiation into osteoblasts, and growth promoters, which accelerate bone production by these newly differentiated cells. The cancellous graft heals by a combination of formation of new bone by the transplanted osteoblasts, followed by the formation and remodeling of new bone by the cells recruited from the periphery.

The corticocancellous block graft provides transplanted osteoblasts and growth factors as well as structural rigidity, which is frequently required when implants are placed simultaneously. However, the cortical portion of the graft is slow to revascularize and thus may be more prone to infection. The structural rigidity of the graft allows accurate implant placement, independent of the thickness of the sinus floor.

The healing of these bone grafts follows a course of events that starts with basic wound healing, and follows with bone remodeling.²⁶ Phase 1 bone healing includes osteoid production and cellular proliferation. Phase 2 includes remodeling of the disorganized phase 1 osteoid and replacement with lamellar bone.

In autogenous grafts, surviving osteoblasts and other cells are responsible for primary bone production.²⁷ These transplanted cells survive through diffusion of nutrients during the first 4 days of transplantation, during graft revascularization.²⁸ The amount of bone eventually produced by the transplanted cells is directly proportional to the density of the surviving endosteal

osteoblasts.²⁹ Initially bone is produced by the endosteal cells on the transplanted trabecular bone. As more osteoid is produced, the graft becomes fused with new bone. The process of graft strengthening and consolidation takes 4 to 6 weeks in the human.

Phase 2 bone is not derived from the transplanted cells. It is produced from recruited host cells, which, through a bone remodeling sequence, replace the transplanted cells. The osteoid produced during phase 1 bone production is removed by osteoclasts, which are brought to the graft site by newly formed blood vessels. As phase 1 bone is resorbed, it is replaced by a new trabecular ossicle with a well-defined lamellar form with an endosteum and periosteum, able to remodel according to the forces placed on it as described by Wolfe's law.³⁰

Particulate cancellous grafts undergo a more rapid replacement of the phase 1 bone than do cortical grafts, because the particulate graft is revascularized sooner than a cortical graft. Cortical bone must be resorbed prior to becoming revascularized. During the resorptive phase, the cortical bone graft becomes weaker because of loss of mineralization through Haversian resorption and creeping substitution of new bone.^{30,31} However, the cortical graft still maintains sufficient rigidity to maintain implant position.

Autogenous cancellous bone can be harvested from any bone with a marrow space, including the tibia, chin, retromolar region, and maxillary tuberosity. It is recommended that the cancellous bone be compacted prior to its placement to increase the density of the transplanted cells.^{30,31} Firm compaction of the cancellous particles against the sinus floor is utilized to further compact the graft. Use of blocks of symphyseal bone has been advocated for both sinus grafts and onlay grafting, because symphyseal bone is membranous and presumably less prone to resorption than to iliac crest bone.¹⁰

Autogenous Bone Combined with Demineralized Bone

Demineralized bone is bone that has had its mineral removed through an acid treatment and then is washed and lyophilized until reconstituted for use. When autogenous bone is demineralized, the remaining organic substrate contains bone morphogenetic protein.³² Neighboring mesenchymal cells receive a signal from this protein complex, which initiates cytodifferentiation to form cells capable of forming bone. The process of bone production from osteoinduction is dependent on oxygen tension, which relies on the vascular status of the wound. When demineralized bone is placed in a region of low oxygen tension, fibrous or cartilage tissue results rather than bone.³²

Because the amount of autogenous bone available from the jaws may be limited, demineralized bone can be combined with autogenous bone to expand the graft's volume. This combination of autogenous bone expanded with allogeneic demineralized bone is a useful method for obtaining phase I bone formation from the autogenous bone graft as well as phase II bone formation from the demineralized bone, and establishing the bulk of the graft.^{33,34}

Method and Materials

Population studied

Of 31 patients, 18 who had had autogenous bone placed in their sinuses prior to February 1991, 16 were able to be recalled for tomography of their sinuses. The 15 patients unable to be recalled included those who moved, did not desire to spend the time required for the examination, or did not feel that additional exposure to radiation was warranted because they had no complaints.

These 16 patients (nine females and seven males; mean age of 48.5 $\pm$ 16.0 years, range of 14 to 74 years) had 27 sinus grafts performed. The implants placed into the patients were all hydroxyapatite-coated cylinders or screws. Of the 70 implants imaged in this study, 47 were cylinders (Calcitek). Six of these implants were 10 mm long, 28 were 13 mm long, and 13 were 15 mm long. Thirty-five implants were 4.0 mm in diameter, and 12 implants were 3.25 mm in diameter. The other 23 implants were screws (Steri-Oss). Of these, 16 were 14 mm long and seven were 16 mm long, and all were 3.8 mm in diameter.

Surgical technique

The surgical technique has been described in previous publications.^{3,18} The lateral wall of the maxilla was rotated intact with the sinus membrane. Small tears in the sinus membrane were not treated; however, larger tears were covered with a collagen membrane. No membranes were used to cover the lateral wall defect after the bone graft was placed.

The graft types for the imaged patients were grouped as:

1. Iliac crest particulate cancellous grafts alone (IIPart), $n = 6$.
2. Iliac crest particulate cancellous grafts combined with demineralized bone (DMB), 1:1 ratio (IIPart + DMB), $n = 6$.
3. Iliac corticocancellous blocks alone (IIBlock), $n = 8$.
4. Iliac corticocancellous blocks with particulate can-

cellous bone combined with DMB, 1:1 ratio, as a filler (IIBlock + IIPart + DMB), $n = 2$.

5. Autogenous cancellous jaw grafts (one chin and four tuberosity) combined with DMB, 1:1 ratio (Jaw + DMB), $n = 5$.

All implants were placed at the same time as the graft procedure. The implants were exposed 6 months after placement (Figs 11-1 to 11-3).

Prosthetic rehabilitation

Eight patients had overdentures made over a bar that was secured to the implants with screws. The bars were cross-arch stabilized in four patients and not cross-arch stabilized in four patients. Five patients had two- to four-unit porcelain-fused-to-metal fixed restorations placed on the implants. Two patients had fixed complete-arch restorations, one a porcelain-fused-to-metal prosthesis and one a hybrid-type prosthesis with acrylic resin teeth. One patient was never restored because of financial problems.

Of the 73 implants placed in these patients, three have been removed. Two were in a patient who suffered a myocardial infarction and developed crestal bone loss, resulting in implant loosening. One implant was removed in another patient who lost an implant because of crestal bone loss without an obvious reason. The analysis involved the 70 implants remaining for imaging.

Tomography technique

The tomography machine used in this study was the computer-aided CommCat Model IS-2000e Tomographic System (Imaging Sciences International). This tomography unit provides complex-motion tomography using the Grossman technique, providing distortion-free images with constant magnification. Slice thickness is selectable from 1 mm to infinity. Pieces of metal show up without the starburst effect of computerized tomography, and gray levels in the image give a good indication of bone quality as well as dimensions. The exposure time is 3 to 6 seconds, the radiation received per slice is 0.50 to 0.75 mSv, and the focal spot size is 0.5 mm.

Complex-motion tomography was chosen as the method for quantifying bone levels in this study because of its advantages over panoramic radiography.³⁵⁻⁴¹ In the latter, the x-ray beam travels at an angle to the patient's head and therefore produces distortion of the images. The placement of the object in the focal trough and the speed of rotation of the film also produce distortion of the images. With the IS-2000e tomography

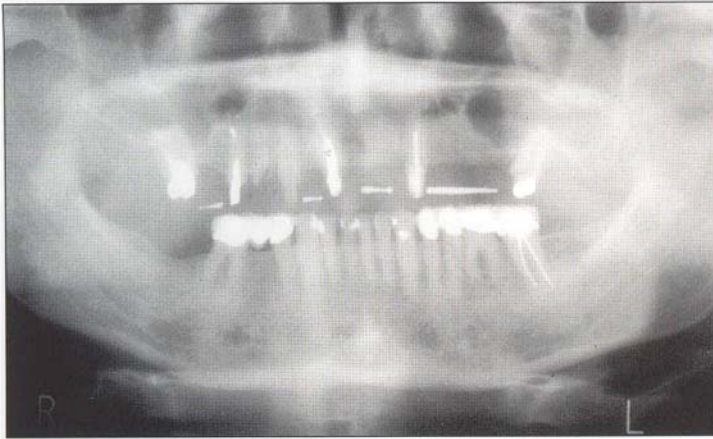


Fig 11-1a Preoperative panoramic radiograph.



Fig 11-1 b Occlusal view of maxilla prior to the sinus grafting procedure.

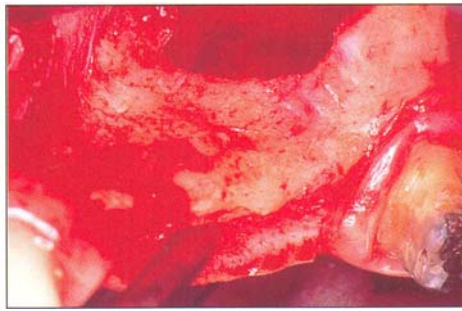


Fig 11-1 c An incision is made over the crest with vertical release. The lateral wall of the maxilla has been rotated medially in preparation for the sinus graft.

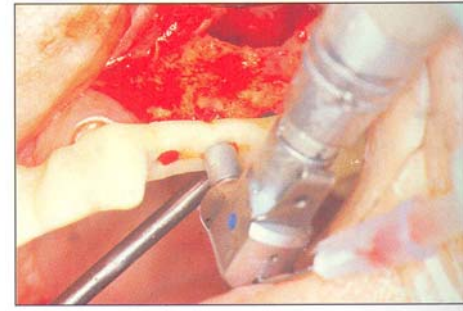


Fig 11-1 d Because the patient has more than 3 mm of crestal bone, the template is placed and the implant sites are prepared.

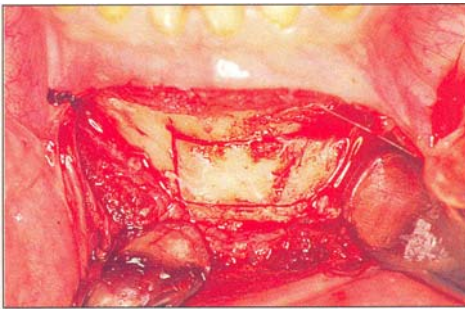


Fig 11-1 e The chin is approached through a vestibular incision, and a sagittal saw is used to outline the cortex, which is then removed.

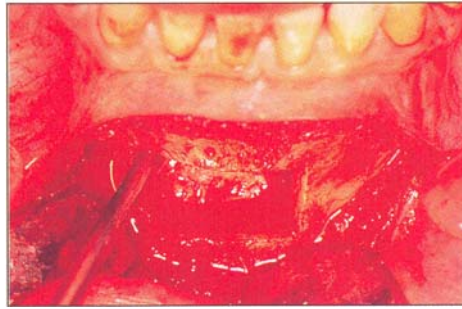


Fig 11-1 f Cancellous bone is harvested from the chin.

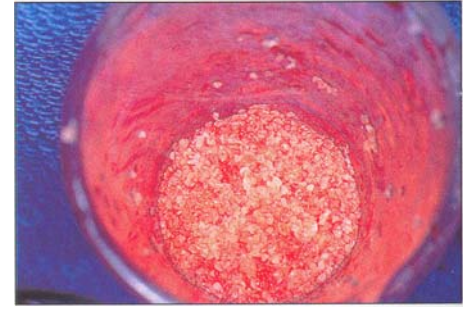


Fig 11-1g The cancellous bone is particulated and combined with an equal volume of demineralized bone.

machine, there is zero distortion because of the use of the Grossman technique. This technique, in which the linkage between the x-ray source and the film holder keeps the focal plane parallel to the film plane at all times, produces distortion-free slices.

In panoramic radiography, horizontal and vertical magnification of the images is uneven. This uneven magnification in horizontal and vertical dimensions varies in different parts of the jaws. Therefore, it is not possible to use correction magnification factors to determine the

exact dimensions of the object. All measurements made on a panoramic radiograph will be erroneous. With the 15-2000 tomography machine, the magnification is constant and fixed at 26% in all directions. Therefore, any measurement made from a tomogram is multiplied by a correction factor to obtain the exact object measurement. This makes tomography a useful tool in measuring implant sites. Finally, in panoramic radiography, the image slice is thick, thus causing several anatomic layers to be superimposed on each site.



Fig II-lh The bone is placed in the sinus with the membrane elevated. The implants are placed, and additional bone is placed over the implants and the thin alveolar ridge.

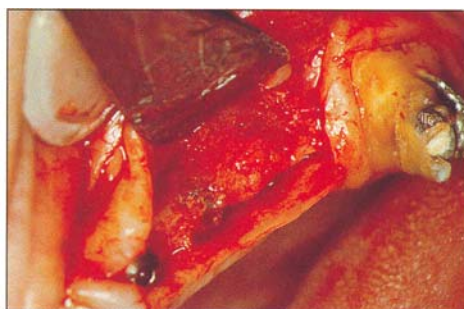


Fig II-li Six months later, a crestal incision bisecting the keratinized gingiva is used to expose the implants.



Fig II-lj A rongeur forceps is used to expose the implants, which were covered with healing bone.



Fig 11-lk The gingiva is sutured around temporary healing abutments.

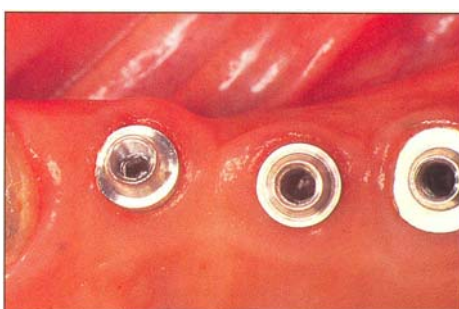


Fig 11-li Occlusal view of the tissue around the implants.



Fig 11-lm Lateral view of the implant-supported restoration. (Prosthetics by Dr Gerard Chiche.)

Maxillary implant tomography technique

A dental cast of the patient's maxillary teeth was scanned into the computer. The computer was linked to the tomography machine so that it controlled the movements of the tubehead. The scanned image of the maxillary dental arch was mapped on the computer so that the slice markings were at 1-mm intervals. The angle of each slice varied according to its location in the dental arch.

Multiple cross-sectional cuts were made at each implant site. The total number of cross-sectional cuts and the distances between these cuts were determined for each patient based on the location and number of implants. For orientation purposes, a sagittal cut was made for every four cross-sectional cuts. All tomograms were made using the hypocycloidal tube motion. Crosssectional cuts were 2-mm thick, whereas the sagittal cuts were 6-mm thick.

All measurements were made on cross-sectional tomograms using a measuring scale that was magnified by a factor of 0.793. This magnification factor compensated for the 26% magnification in the tomograms.

Analysis of radiographs

The amount of bone present or absent from the apex of the implant was measured with a millimeter ruler corrected for the 26% magnification of this machine. Bone level distance measurements recorded included the height of the sinus graft to the alveolar crest (bone level 1 [BL1]) and the height of the graft to the apical aspect of the implant (bone level 2 [BL2]). A positive value for bone-to-apex distance indicated that bone was present superior to the implant's apex. A negative distance indicated that the bone level was inferior to the implant's apex, with a portion of the implant not covered with bone. The measurements were made by one investigator, who was not involved with treatment of these patients. Five implants were not clearly visible in the tomograms because of overlap with other implants and were not measured. The bone levels for patients augmented with hip bone were compared to bone levels for patients with grafts harvested from the jaws (Figs 11-30, 11-4 and 11-5).

11 Simultaneous Placement of Hydroxyapatite-Coated Implants

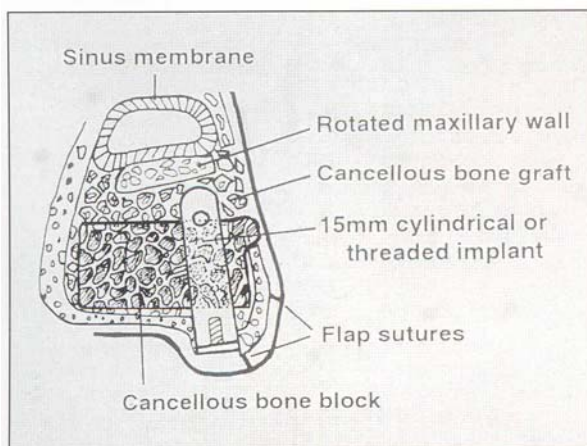


Fig 11-2a Method for treating the following patient, who has less than 1 mm of alveolar bone height. A block of bone will be used to support implants placed simultaneously with the graft.

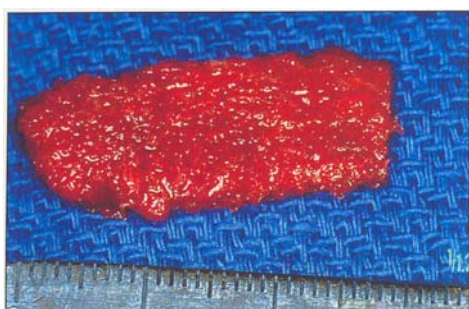


Fig 11-2b Cancellous bone harvested from the iliac crest.



Fig 11-2c The cancellous bone is placed into the sinus after the lateral wall of the maxilla and the sinus membrane have been elevated. After placement of the cancellous bone block, the implant sites are prepared in a customary manner.



Fig 11-2d The graft and implants are in place. Additional cancellous bone was placed to cover the superior portion of the implants and fill in voids.



Fig 11-2e Lateral cephalogram showing the parallel placement of the implants.

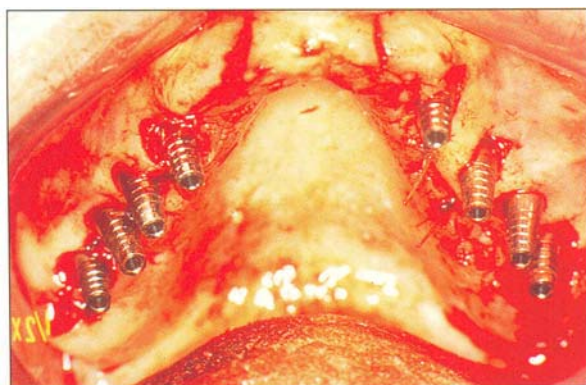


Fig 11-2f After 6 months, the implants are exposed and abutments are placed.

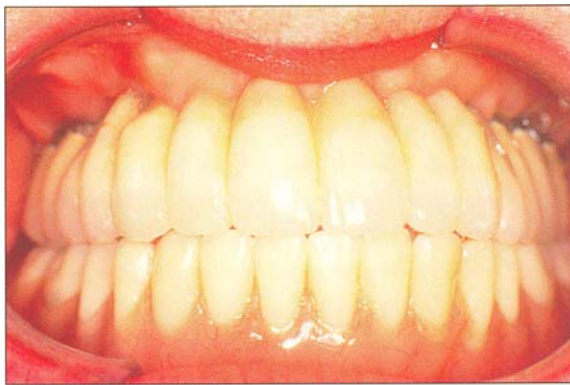


Fig 11-2g Fixed restoration in place. (Prosthetics by Dr Larry McMillen.)

Fig II-3a Maxilla of man who complained of inability to wear his maxillary denture and comfortably chew hard food. His physical examination revealed flabby anterior maxillary soft tissue and severe maxillary atrophy.

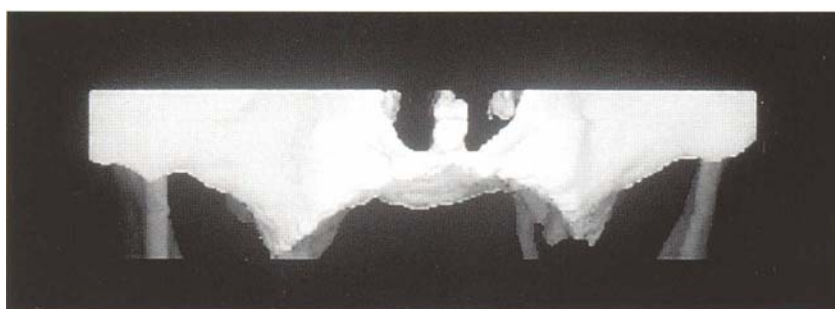
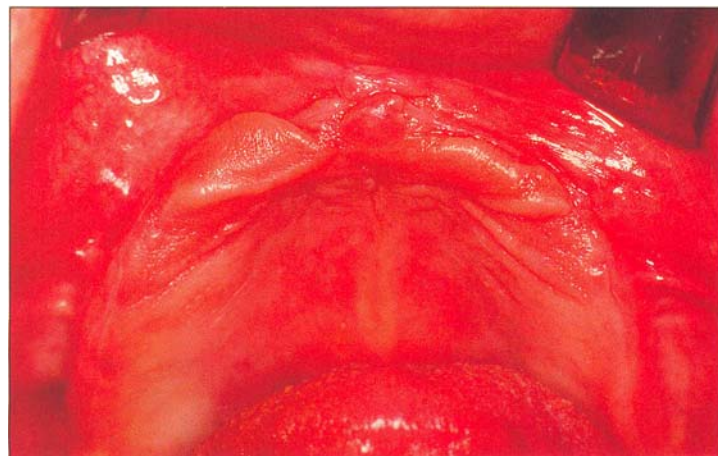


Fig II-3b Three-dimensional reconstructed computerized tomography scan (Columbia Scientific Software) demonstrating severe anterior maxillary resorption, consistent with his opposing anterior mandibular intact dentition.

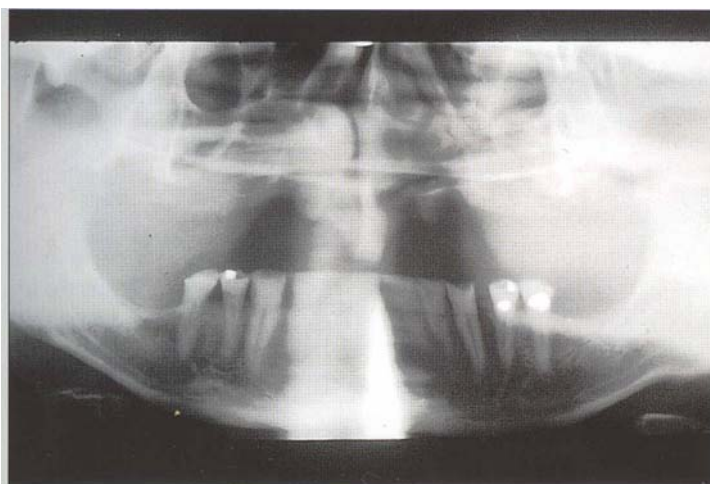


Fig II-3c Panoramic radiograph showing the intact anterior mandibular teeth without posterior occlusion, resulting in severe anterior maxillary atrophy.

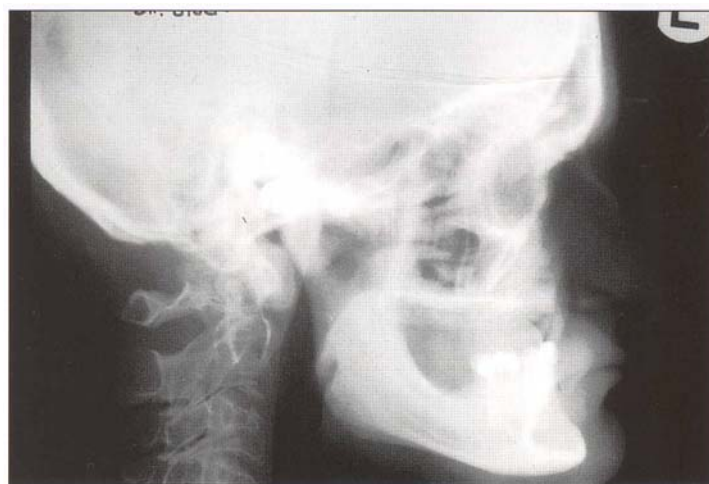


Fig II-3d lateral cephalogram showing the closed vertical dimension and flat occlusal plane.

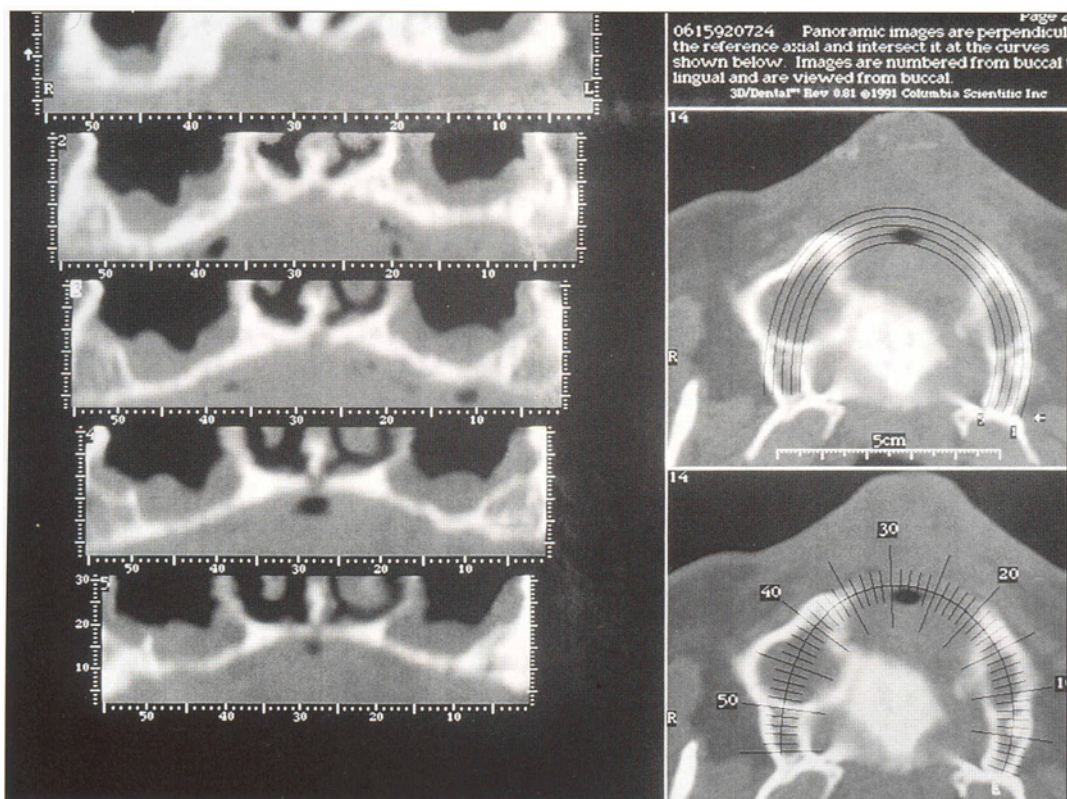


Fig 11-3e Reconstructed panoramic views showing the posterior and anterior severe maxillary atrophy. Without a bone graft, insufficient bone is present for placement of implants in the maxilla.

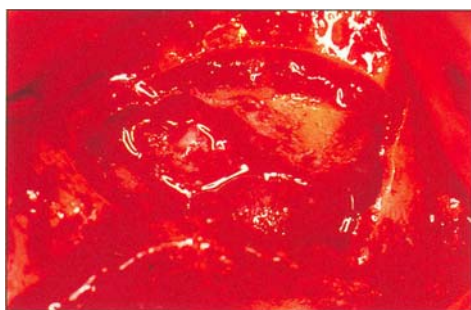


Fig 11-3f Bilaterally, the lateral wall of the maxilla is rotated medially with elevation of the sinus membrane.

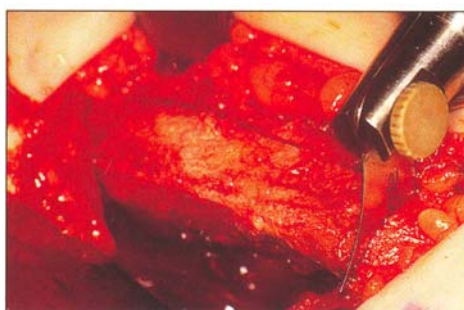


Fig 11-3g Corticocancellous blocks are harvested from the anterior iliac crest.



Fig 11-3h The bone blocks are trimmed to fit within the sinus and retained with hydroxyapatite-coated threaded implants.



Fig 11-3i Four implants are placed into each graft on both sides of the maxilla.



Fig 11-3j After the sinus grafts are completed, the anterior maxillary defect is examined.

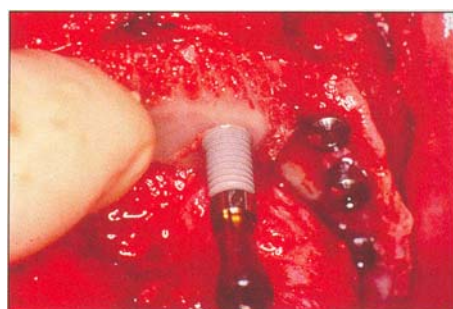


Fig 11-3k A block of bone is screw retained to the anterior maxilla, using two hydroxyapatite-coated threaded implants.

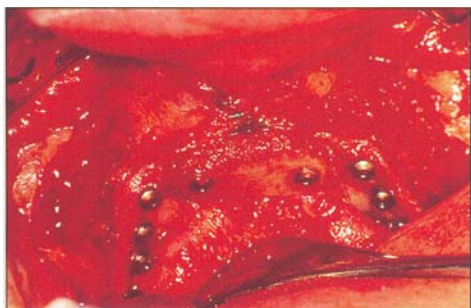


Fig 11-31 The reconstruction is completed.

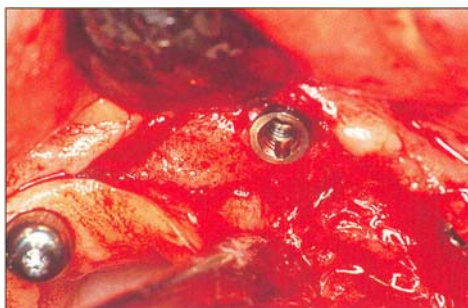


Fig 11-3m After 6 months, excellent bone is present over the anterior implants placed in the onlay bone graft.



Fig 11-3n Spark-erosion prosthesis was made over the implants, and the vertical dimension of occlusion was increased gradually with a splint when a new mandibular prosthesis was made. (Prosthetics by Dr Israel Finger.)



Fig 11-30 Five-year follow-up complex-motion tomogram of implants. (Left) Left posterior. (Right) Right posterior. Arrows indicate bone at apical region of implants.



Fig 11-4a Preoperative panoramic radiograph of a patient prior to receiving a sinus graft composed of maxillary tuberosity bone combined 1: 1 by volume with demineralized bone particles.

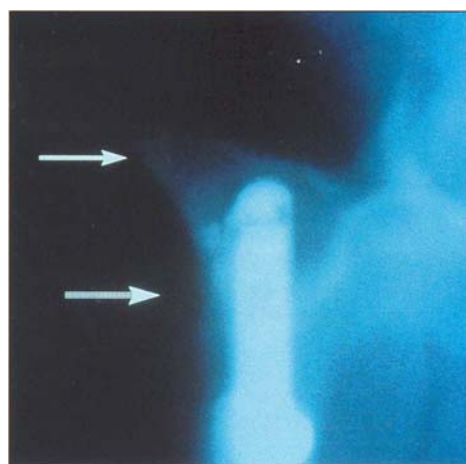


Fig 11-4b Seven-year postrestoration complex-motion tomogram showing maintenance of bone placed in the sinus. Apical bone level (top arrow); original bone level (bottom arrow).

Fig II-5a Ten-year post-restoration tomogram of implants placed simultaneously with iliac crest cancellous bone particles (right side).

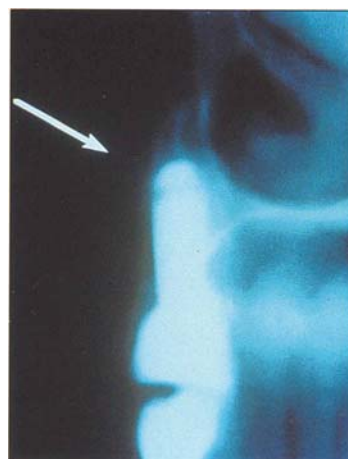


Fig II-5b Ten-year postrestoration tomogram of implants placed simultaneously with iliac crest cancellous bone particles (left side). Arrow points to bone at apical region of implant.

Statistical methods

The analysis was performed on all of the grafts combined, all of the iliac bone grafts combined, and for the four groups previously described. The IIBlock and the IIBlock + Part + DMB groups were combined in the analysis because of the small sample size of the IIBlock + Part + DMB group and the large amount of block graft used in relation to particulate and demineralized bone grafting material. In the estimation of the surgeons at the time of grafting, less than 20% of the total graft was particulate plus demineralized bone material.

The statistical analysis evaluated only the tomograms for the amount of bone remaining around the implants and from the alveolar crest. Bone levels for the panoramic radiographs were not evaluated statistically because of the large errors inherent to them.

Results

The bone heights measured from panoramic radiographs are included only for a qualitative examination.

All grafts _ombined

The data for all patients are presented in Table 11-1. The average height of grafted bone to ridge crest was 17.6 $\pm$ 3.1 mm and the average height of grafted bone to implant apex was 3.3 $\pm$ 3.1 mm.

Jaw + DMB graft

The data for patients who had their sinuses grafted with bone harvested from the chin, maxillary tuberosity, or ramus, combined with demineralized bone in a 1:1 ratio, are described in Table 11-2. The average height of grafted bone to ridge crest was 16.9 $\pm$ 2.8 mm, and the average height of grafted bone to implant

apex was 2.3 $\pm$ 1.9 mm. The height of grafted bone to implant apex ranged from -2 to 5 mm. Two of 13 implants had negative values, indicating that a portion of the implant was not covered with bone.

Iliac bone graft (all combinations)

The data for patients who had their sinuses grafted with bone harvested from their iliac crest are described in Table 11-3. This includes all combinations of particulate marrow, with or without the addition of demineralized bone, and corticocancellous blocks of bone. The average height of grafted bone to ridge crest was 17.7 $\pm$ 3.2 mm, and the average height of grafted bone to implant apex was 3.5 $\pm$ 3.3 mm. The height of grafted bone to implant apex ranged from -9 to 9 mm. Four of 57 implants had negative values, indicating that a significant portion of the implant was not covered with bone.

IIPart graft

The data for patients who had their sinuses grafted with particulate iliac marrow alone are described in Table 11-4. The average height of grafted bone to ridge crest was 18.4 $\pm$ 1.8 mm, and the average height of grafted bone to implant apex was 5.4 $\pm$ 2.0 mm. The height of grafted bone to implant apex ranged from 2 to 9 mm. No implants had negative values, indicating that, in this group, all implants were covered with bone.

IIPart + DMB graft

The data for patients who had their sinuses grafted with particulate iliac marrow, combined with demineralized bone in a 1:1 ratio, are described in Table 11-5.

Table 11-1 Bone levels for implants in all recalled patients combined

	Preop ridge height	Immediate postop BL1*	Immediate postop BL2†	Immediate postrestoration BL1	Immediate postrestoration BL2	Longest follow-up BL1	Longest follow-up BL2
Mean	5.1	20.1	6.0	18.3	4.2	17.6	3.3
SD	2.2	2.4	2.3	2.6	2.8	3.1	3.1
No.	78	78	78	56	56	70	70
Image type	Pano	Pano	Pano	Pano	Pano	Torno	Torno

* BL1 = bone level from the sinus graft to the alveolar crest.

† BL2 = bone level from the sinus graft to the apical aspect of the implant.

Pano = panoramic radiograph; Torno = tomogram.

Table 11-2 Bone levels for implants in patients grafted with jaw bone (Jaw + DMB)

	Preop ridge height	Immediate po stop BL1*	Immediate postop BL2†	Immediate postrestoration BL1	Immediate post restoration BL2	Longest follow-up BL1	Longest follow-up BL2
Mean	6.8	19.6	4.7	17.2	2.3	16.9	2.3
SD	1.7	3.0	1.2	2.8	2.0	2.8	1.9
No.	13	13	13	13	13	13	13
Image type	PanG	Pano	PanG	PanG	PanG	Torno	Torno

Table 11-3 Bone levels for implants in patients grafted with iliac bone (all combinations)

	Preop ridge height	Immediate po stop BL1*	Immediate po stop BL2†	Immediate postrestoration BL1	Immediate postrestoration BL2	Longest follow-up BL1	Longest follow-up BL2
Mean	4.8	20.2	6.5	18.6	4.7	17.7	3.5
SD	2.3	2.2	2.1	2.5	2.8	3.2	3.3
No.	61	61	61	41	41	57	57
Image type	PanG	PanG	PanG	PanG	PanG	Torno	Torno

Table 11-4 Bone levels for implants in patients grafted with particulate iliac marrow alone (IIPart)

	Preop ridge height	Immediate postop BL1 *	Immediate postop BL2+	Immediate post restoration BLI	Immediate postrestoration BL2	Longest follow-up BL1	Longest follow-up BL2
Mean	4.8	20.2	8.1	19.5	7.2	18.4	5.4
SD	1.3	3.1	2.7	2.9	3.1	1.8	2.0
No.	14	14	14	11	11	13	13
Image type	PanG	PanG	PanG	PanG	PanG	Torno	Torno

Table 11-5 Bone levels for implants in patients grafted with particulate iliac crest marrow combined with 1: 1 demineralized bone (IIPart + DMB)

	Preop ridge height	Immediate po stop BL 1 *	Immediate postop BL2†	Immediate postrestoration BL1	Immediate postrestoration BL2	Longest follow-up BL1	Longest follow-up BL2
Mean	5.6	18.5	4.9	16.6	3.0	15.3	1.2
SD	2.7	1.9	1.5	0.5	0.8	5.3	5.1
No.	14	14	14	8	8	12	12
Image type	Pano	Pano	PanG	PanG	PanG	Torno	Torno

The average height of grafted bone to ridge crest was 15.3 ± 5.3 mm, and the average height of grafted bone to implant apex was 1.2 ± 5.1 mm. The height of grafted bone to implant apex ranged from -9 to 7 mm. Two of 12 implants had negative values, indicating that a significant portion of the implant was not covered with bone.

IIBlock graft (combines IIBlock and IIBlock + Part + DMB groups)

The data for patients who had their sinuses grafted with corticocancellous blocks of iliac bone are described in Table 11-6. The average height of grafted bone to ridge crest was 18.3 ± 2.3 mm, and the average height of grafted bone to implant apex was 3.5 ± 2.3 mm. The height of grafted bone to implant apex ranged from -2 to 8 mm. Two of 33 implants had negative values, indicating that a portion of the implant was not covered with bone.

Statistical analysis

When the tomogram-derived data were analyzed, statistically significant differences were found between graft types (Table 11-7). The general linear models procedure of analysis of variance (SAS statistical system) was used to evaluate the tomographic data and compare the two bone level measures between groups.

Bone level 1

Analysis of variance indicated that there was a significant difference between graft types ($df = 3$; F value = 3.23; $P = .0279$). The IIPart + DMB group had significantly different, smaller bone levels than did the IIBlock group and the IIBlock group (Duncan's multiple range test: $\alpha = .05$; $df = 66$; $MSE = 9.162$).

Bone level 2 .

Analysis of variance indicated that there was a significant difference between graft types ($df = 3$; F value = 5.02; $P = .0034$). The IIPart + DMB group had significantly different, smaller bone levels than did the IIBlock group and the IIPart group. The Jaw + DMB group had significantly different, smaller bone levels than did the IIPart group (Duncan's multiple range test: $\alpha = .05$; $df = 66$; $MSE = 8.32$).

Discussion

This study shows that the bone that forms in autogenous bone-grafted sinuses can be retained. This population received simultaneous placement of hydroxyapatite-coated implants (cylinders and screw shaped) with their grafts. Five to 10 years later, bone was still present around and above the apex of the implants. Of the 70 implants examined, 90% (63/70) of the implants had bone covering the apex of the implant. This result supports the use of autogenous bone for sinus grafting.

Residual alveolar bone thickness at the time of sinus graft did not affect the procedure performed, except that thin ridges (less than 3 mm) were augmented with block iliac crest grafts rather than particulate cancellous grafts. When stability and parallelism of implants are questionable with thin ridges, then proper technique suggests the use of blocks for stability. Unfortunately, the preoperative radiographs were panoramic, which do not allow quantitative analysis of the difference in initial ridge height and ultimate ridge height. However, at surgery, several of these patients' ridges measured less than 2 mm thick prior to their graft. Although difficult to quantify, the impression was that the initial alveolar bone ridge was maintained throughout the study.

One patient, who lost two of four implants, had significant resorption of the sinus bone graft, with only the 5 mm of initial ridge remaining and 9 mm of implant not covered by bone, according to the radiograph. Four patients had 2 mm of exposed implant because of resorption of the graft, with 13 mm of implant still encased in bone. The surgical technique used in our institution is now confirmed to result in longterm bone heights on implants.

We have been placing implants simultaneously with the autogenous bone graft in the sinus since 1985. The rationale was based on evidence that, after 6 months, onlay iliac crest grafts resorb. We were concerned that significant resorption of the graft could occur after the initial 6 months of healing, unless the grafts were loaded and stimulated. It was our belief that restoring the implants would stimulate the bone grafts, preserving the bone placed in the sinus. After 6 months of healing, the bone in these grafts did respond positively to forces placed on it. This study indicates that bone maintenance at the height of the implant has been achieved.

The differences between graft types indicated that the addition of demineralized bone to the iliac grafts lowered the eventual bone level slightly. Although this difference was statistically significant, the clinical difference was small, because the implants were still covered with bone. There are clinical situations when the amount of bone harvested from the donor site is less than ideal. In these situations, demineralized bone was

Table 11-6 Bone levels for implants in patients grafted with corticocancellous blocks of iliac crest (IIBlock combined with IIBlock + Part + OMB)

	Preop ridge height	Immediate postop BL1*	Immediate postop BL2†	Immediate post restoration BL1	Immediate postrestoration BL2	Longest follow-up BL1	Longest follow-up BL2
Mean	4.5	21.0	6.6	18.8	4.1	18.3	3.5
SD	2.4	1.5	1.5	2.4	2.3	2.3	2.3
No.	33	33	33	22	22	32	32
Image type	Pano	Pano	Pano	Pano	Pano	Tomo	Tomo

* BL1 = bone level from the sinus graft to the alveolar crest.

† BL2 = bone level from the sinus graft to the apical aspect of the implant.

Pano = panoramic radiograph; Tomo = tomogram.

Table 11 _7 Longest follow-up height of grafted bone to ridge crest (BL1) and height of grafted bone to implant apex distance (BL2)

Bone graft type	BL1			BL2		
	Mean	SD	n	Mean	SD	n
Jaw + DMB	16.9	2.8	13	2.3†	1.9	13
IIPart	18.4 *	1.8	13	5.4*†	2.0	13
IIPart + DMB	15.3*	5.3	12	1.2*	5.1	12
IIBlock	18.3 *	2.3	32	3.5*	2.3	32

* Significant difference between IIPart + DMB and the IIPart and IIBlock groups ($P < .05$). †

Significant difference between Jaw + DMB and IIPart groups ($P < .05$).

added to increase the volume of the graft. In this series, however, the addition of demineralized bone did not increase the eventual graft volume long term.

This study examined bone maintenance in patients after 5 to 10 years of function on the implants placed in autogenous bone-grafted sinuses. No attempt was made to differentiate prosthesis design, length and diameter of implants, or small variations in surgical technique, such as antibiotic coverage, flap design, or type of implants used. In this patient series, failure of the implants and grafts has been rare. The prostheses fabricated for these patients followed well-known techniques for their restoration.

Conclusion

Bone was maintained at the level of the apex of the implant in this series of patients treated with autogenous bone grafts and simultaneous placement of hydroxyapatite-coated implants.

Acknowledgment

The study described in this chapter was previously published in the *Journal of Oral and Maxillofacial Surgery* in the following two articles: Block MS, Kent IN. Sinus augmentation for dental implants: The use of autogenous bone (1997;55:1281-1286). Block MS, Kent IN, Kallukaran FU, Thunthy K, Weinberg R. Bone maintenance 5 to 10 years after sinus grafting (1998;56:706-714).

Recombinant Human Bone Morphogenetic Protein-1 for Maxillary Sinus Grafting

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Dental reconstruction of the posterior maxilla is frequently difficult because of alveolar bone loss and increased maxillary sinus pneumatization, which occur with the loss of premolar and molar teeth. Restoration of this bone loss may require bone-grafting procedures to recreate the bone height and width. These procedures include onlay grafting and maxillary sinus floor grafting. Various materials have been used for this purpose, including autologous bone, allogeneic bone, alloplastic bone substitutes, and combinations of these materials.¹⁻⁴ Currently, autologous grafting is the gold standard, but patient acceptance may be limited because of the cost, time involved, postoperative morbidity, and limitation of activity for a 2- to 4-week period following donor harvesting (ie, ilium or tibia). Dental practitioners have been experimenting for years with various bone substitutes to increase patient acceptance of the reconstructive procedures and to reduce the surgical morbidity and limitations associated with autologous grafting.

Recombinant human bone morphogenetic protein² (rhBMP-2) is an osteoinductive protein that, when administered locally, results in the induction of new bone tissue at the site of implantation. A large number of preclinical studies using a variety of animal models have demonstrated that rhBMP-2, when combined with a variety of delivery systems, can heal critical-sized cranial, long bone, and mandibular defects.⁵⁻⁷ In addition, preclinical studies have demonstrated the ability of rhBMP-2 to augment alveolar bone in dogs and in maxillary sinus floor grafting procedures in the goat.^{8,9}

A recent human study of maxillary sinus floor grafting has demonstrated the ability of rhBMP-2, de-

livered on an absorbable collagen sponge (ACS), to induce new bone formation in the sinus without adverse sequelae.¹⁰ Additional clinical studies are currently in progress to determine the safest and most effective dose of rhBMP-2 for bone induction and to determine the ability of the newly induced bone to successfully support endosseous dental implant-borne restorations after functional loading.

The first human clinical study to evaluate rhBMP2/ACS was a prospective multicenter open-label feasibility study.¹⁰ Twelve patients who had inadequate bone height in the posterior maxilla, and who were candidates for a two-stage maxillary sinus floor augmentation procedure, were enrolled. The objectives of this study were to evaluate the short-term safety and technical feasibility of rhBMP-2/ACS implantation and to assess various methods to measure bone induction. The protocol was conducted following US Food and Drug Administration and institutional review board approval. The method and materials as well as the data generated from the initial phase of this study are presented in this chapter.

Method and Materials

Surgical technique

The sinus graft procedure is performed after administration of sedation and local anesthesia for patient comfort. To approach the lateral maxillary sinus wall, incisions are made over the crest of the posterior max

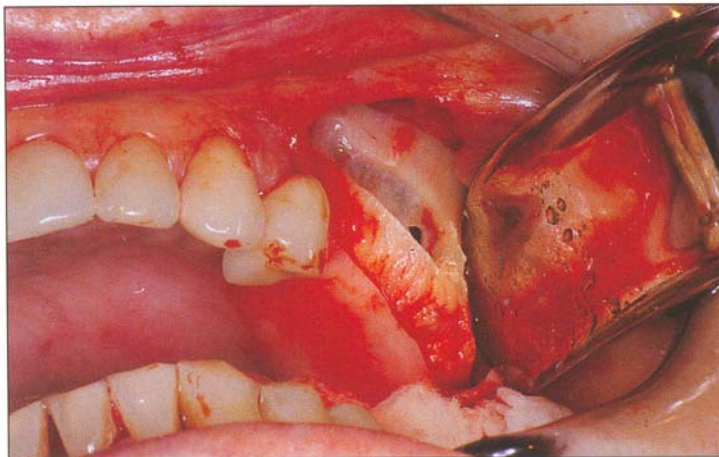


Fig 12-1 Outline of the sinus window.

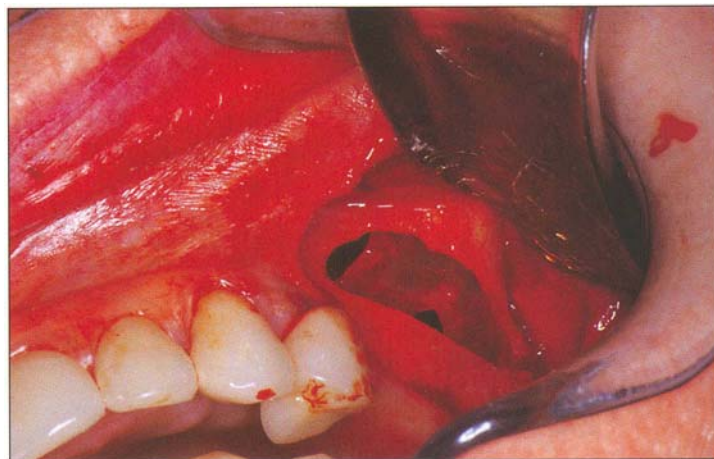


Fig 12-2 Window and membrane elevation.

illary alveolus and extended anteriorly to the canine region. A vertical releasing incision is made anterior to the most anterior extent of the maxillary sinus, which is determined with radiographs. If necessary, a posterior releasing incision is made in the area of the tuberosity.

Number 12 round burs or round diamond stones may be utilized in a surgical handpiece to outline a window in the lateral maxillary wall, which will be used to enter the sinus. The sinus membrane is exposed and carefully dissected from the sinus floor walls. Either a sinus wall infracture technique or a total removal of the lateral osseous wall may be used. The sinus membrane is dissected free from the lower two thirds of the sinus cavity (Figs 12-1 and 12-2).

The rhBMP-2/ACS device consists of two components: rhBMP-2 and Helistat Absorbable Collagen Hemostatic Sponge (Integra Life Sciences). The rhBMP-2 portion of the device is the osteoinductive factor that stimulates host bone formation; the carrier component, the ACS, consists of bovine type 1 collagen and provides the matrix for delivery for rhBMP-2. A dry 7.5 x 10.0-cm collagen sponge is soak-loaded with 8 mL of rhBMP-2 solution (0.43 mg/mL concentration, produced and purified by Genetics Institute). After soak loading, each complete sponge contains 3.4 mg of rhBMP-2 (Fig 12-3a).

Strips of the rhBMP-2/ACS are layered into the exposed sinus cavity to occupy approximately one half to two thirds of its volume (Fig 12-3b). The mucoperiosteal flap is then returned to its original position and secured with sutures.

Standard preoperative and postoperative medications included oral antimicrobial rinses every 12 hours for 7 to 10 days and oral antibiotics (ampicillin/sulbactam [Unasyn, Roerig], amoxicillin/clavulanate [Aug

men tin, SmithKline Beecham], or erythromycin) for 7 to 20 days for infection prophylaxis; decongestant/expectorant (phenylpropanolamine hydrochloride/guaifenesin [Entex LA, Proctor and Gamble]) twice a day for 7 to 10 days for relief of sinus congestion; analgesics for postoperative pain; and steroids/nonsteroidal anti-inflammatory drugs for 2 to 3 days to minimize postoperative swelling.

Evaluations

To evaluate the local and systemic toxic effects of rhBMP-2/ACS implantation, the following procedures were performed: clinical examination; periapical radiography; collection of blood and urine samples to monitor the effect of rhBMP-2/ACS on organ function and on the generation of an immune response; vital signs; and adverse event monitoring.

To assess the feasibility of implanting rhBMP2/ACS, the surgical procedure was documented, and a study device-handling questionnaire was completed.

To assess bone induction, two different standardized radiographic systems to measure bone-inducing activity were evaluated: periapical radiographs and computerized tomographic (CT) scans.

Clinical evaluation

The rhBMP-2/ACS treatment sites were evaluated at 2 and 5 days and 4, 8, 12, and 16 weeks after surgery for common postoperative complications. The parameters evaluated included erythema, exudate, edema, oroantral fistula, wound dehiscence, and complaints concerning the treated sinus (eg, breathing difficulties or sinus pressure).



Fig 12.3a ACS membrane saturated with rhBMP-2.

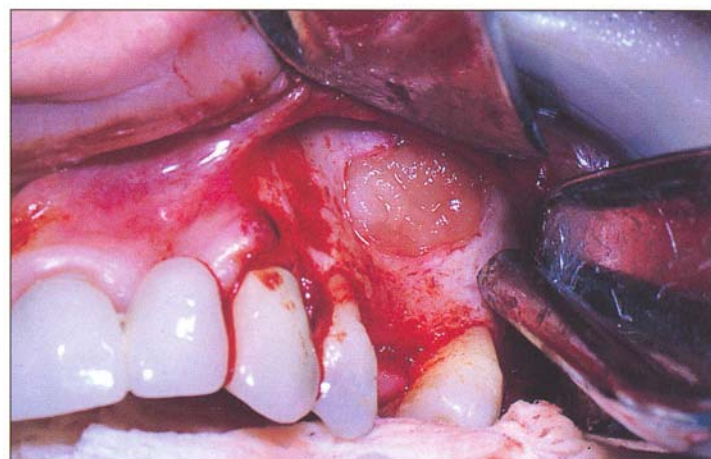


Fig 12.3b Placement of the ACS membrane in the maxillary sinus.

Adverse event surveillance

Adverse events were defined as any sign or symptom occurring during the study of an investigational agent in humans, whether or not it was considered to be related to the investigational agent. Investigators were asked to monitor, document, and assign severity and causality to the adverse events that were reported.

Laboratory evaluation

Blood and urine specimens were collected at baseline (prior to surgery) and at 2 days and 4 weeks postoperatively to evaluate serum chemistries, complete blood count with differential, and urinalysis. Blood specimens were also collected at 5 days and 4, 8, and 16 weeks postoperatively to assess the presence of preexisting antibodies and the generation of an immune response to rhBMP-2/ACS. Serum samples were analyzed by enzyme-linked immunoabsorbant acid (ELISA) for immunoglobulin G, immunoglobulin M, and immunoglobulin A antibodies to rhBMP-2, bovine collagen type 1, and human collagen type 1.

Device-handling questionnaire

The device-handling questionnaire contained seven items relating to the handling characteristics of the device. The investigators were asked to rate each of the characteristics on a scale of 1 to 4, with 4 representing the most favorable rating. The seven categories were cohesiveness, form, handling, volume, placement, ease of preparation, and time of preparation of the rhBMP2/ACS device.

Radiographs

Periapical radiographs were taken at baseline and 4, 8, 12, and 16 weeks postoperatively. Computerized tomographic scans were taken at baseline and 16 weeks postoperatively.

The bone volume of the alveolar ridge is three dimensional: width (buccal to lingual), length (mesial to distal), and height. However, resorption of the ridge is directed across the buccal to lingual aspect (width), as well as apically (height).^{11,12} Therefore, to fully monitor the bone-inducing activity in the rhBMP-2/ACS treatment area, all three dimensions of the alveolar ridge (width, length, and height) were measured.

To remove investigator interpretation bias, measurements on the periapical radiographs and CT scans were made by an independent dental radiology center (University of Texas Health Science Center, San Antonio, Texas). To evaluate the precision of the measurement methods, the measurements were performed by three different radiologists (raters) using the same radiographic film (they were masked to each other's results).

Periapical radiographs. Bone height, length (mesial to distal), and density measurements were obtained from each periapical film. Bone height was measured from the crestal ridge to the base of the sinus floor. Bone length was measured from the mesial to distal aspects of the site to be treated. Bone quality was measured in density units by the use of a reference wedge made of calcium carbonate in epoxy resins (Radiation and Measurements, Inc).

Computerized tomographic scans. Height, width, and density measurements were obtained from two abutting 2-mm cross-sectional multiplanar reformatted images

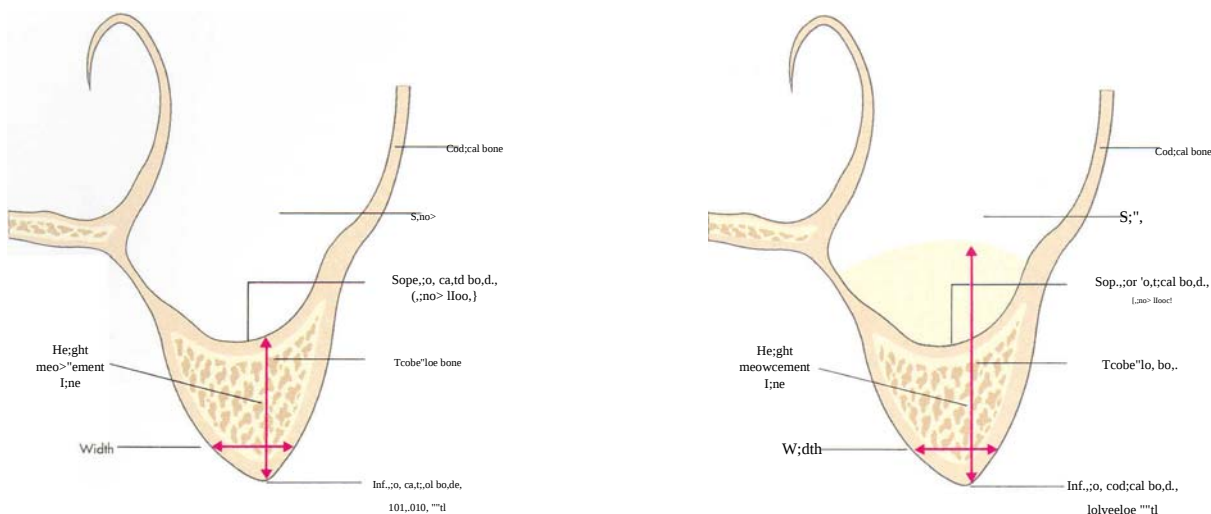


Fig 12-4 Methodology for alveolar ridge height measurement at baseline and 16 weeks postoperatively.

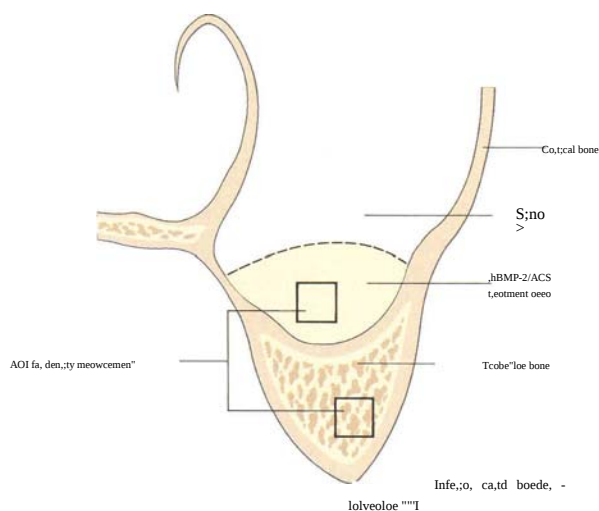


Fig 12-5 Methodology for density measurements.

for each proposed endosseous dental implant site. Bone height was measured along a vertical line drawn parallel to the long axis of the cross section of the maxillary ridge, starting at the alveolar crest and continuing to the antral floor (Fig 12-4).

Bone width (palatal to facial) was measured in the following way. If the patient had a bone height greater than or equal to 12 mm, then the bone width was measured 12 mm from the superior cortical border (sinus floor). If the patient had less than 12 mm but greater

than or equal to 8 mm of bone height, then the bone width was measured 8 mm from the superior cortical border (sinus floor). If the patient had less than 8 mm of bone height, no width measurement was taken.

The quality of the newly induced bone as well as the native bone was assessed by measuring bone density in Hounsfield (H) units. Hounsfield densities are subject to variability between and within CT scanners. To remove this variability, a multiple-density standard block was utilized. The measured values were recorded in H units and normalized using the known mg/cm³ in the standard. Density was measured by identifying the largest possible area of interest box that excluded cortical bone in the native bone at baseline and in the study treatment area at 16 weeks (Fig 12-5).

Core bone biopsies

Full-thickness core bone biopsy specimens of the rhBMP-2/ACS treated area were obtained at the time of endosseous dental implant placement (from those patients who received them) for qualitative histopathologic evaluation. Endosseous dental implants could not be placed before 16 weeks after rhBMP-2/ACS treatment.

An independent laboratory (Bio-Research) was used to process and evaluate the specimens. The bone biopsy specimens were stored immediately after harvesting and shipped in 10% neutral buffered formalin. They were decalcified in formic acid, processed, and embedded in paraffin. Each block specimen was cut into multiple 4-flm-thick longitudinal sections and stained with hematoxylin and eosin.

Both native and newly induced bone were evaluated for the presence of cortical and trabecular bone, the amount and thickness of osseous trabeculae, the location and amount of woven bone, the proportional amount of woven bone remodeling into lamellar bone, and the number of active bone cells (osteoblasts and osteoclasts). Fibrosis, vascularity, mononuclear cell infiltration, and/or mixed inflammatory cell infiltration were graded in the bone marrow.

Data analysis

The local and systemic toxicity of rhBMP-2/ACS was evaluated by reviewing results from oral examinations, radiographs, adverse events (severity, causality, and frequency), and laboratory test results collected at baseline and during the study.

Technical feasibility was evaluated by calculating the minimum, maximum, mean, and median scores for each of the seven handling characteristics mentioned earlier.

Statistical analysis of the measurements from the periapical radiographs was not performed because of missing data points (resulting from difficulties encountered by the clinical sites in obtaining reproducible radiographs) and large variability between the raters' readings (resulting from the raters' inability to identify landmarks from which to take measurements from). However, information concerning the presence of trabecular bone in the rhBMP-2/ACS treated area and congruency of the newly induced bone with the underlying native bone was obtained.

Statistical analyses were performed on the CT scan height measurements to assess whether there was new bone formation due to rhBMP-2/ACS, whether the new bone formation was adequate for dental implant placement, and whether there were substantial differences among the three radiologic raters.

Adequate alveolar bone for dental implant placement at 4 months after rhBMP-2/ACS treatment was assessed in the following way: Optimal bone was defined as greater than or equal to 6 mm wide at the narrowest point (palatal to buccal) and greater than or equal to 13 mm high (inferior to superior cortical border). Minimal bone was defined as greater than or equal to 7 mm wide at the narrowest point and greater than or equal to 8 mm high.

Results

Population

Twelve patients (four men and eight women) between the ages of 26 and 70 years, with a mean age of 51

Table 12-1 Frequent Adverse Events by Body System and COSTART Term

Body system	COSTART* term	No.
Body as a whole	Facial edema	6
Digestive system	Oral erythema	3
	Mouth pain	8
Hemic and lymphatic system	Ecchymosis	2
Respiratory system	Rhinitis	4
	Sinusitis	2

* Coding Systems for a Thesaurus of Adverse Reactions.

years, were enrolled. The majority of the patients were white (eight) and the remaining were African-American (one) or Hispanic (three). Only one of each of the patient's sinuses were treated. None of the patients had underlying medical conditions that are known to affect bone metabolism (an exclusion criterion) at the time of study entry. Six of eight women enrolled in the study were postmenopausal; four of the six were receiving estrogen replacement therapy at the time of surgery.

Safety

The volume of rhBMP-2/ACS that was implanted depended on the perceived size of the patient's maxillary sinus and the surgical antral void created by the surgeon; consequently, the total dose of rhBMP-2 per patient implanted ranged from 1.77 to 3.40 mg (mean of 2.89 mg).

There were no clinically significant changes in vital signs for any of the patients. The only laboratory abnormality was a transient reduction in red blood cell count that may have been related to the surgical procedure rather than to rhBMP-2/ACS treatment.

A total of 28 adverse events were recorded. They were mild-to-moderate in severity, and only five were considered to be related to rhBMP-2/ACS treatment. These five events were one instance each of facial edema, oral erythema, mouth pain, ecchymosis, and sinusitis. The most common adverse events were oral pain (eight patients) and facial edema (six patients) (Table 12-1).

None of the patients developed antibody titers to rhBMP-2 or human type 1 collagen following treatment with rhBMP-2/ACS. Two patients developed an antibody titer to bovine type 1 collagen 8 weeks following rhBMP-2/ACS treatment, but this was not associated with clinical symptoms or lack of bone formation.

There was no evidence of abnormal, overexuberant, or ectopic bone formation on periapical radiographs or CT scans.

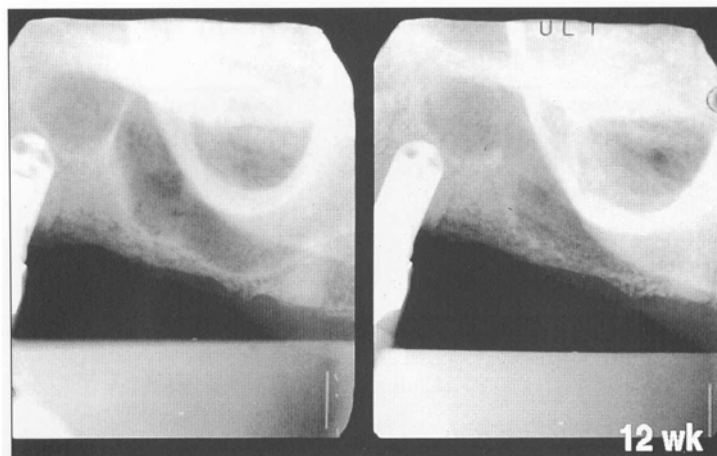
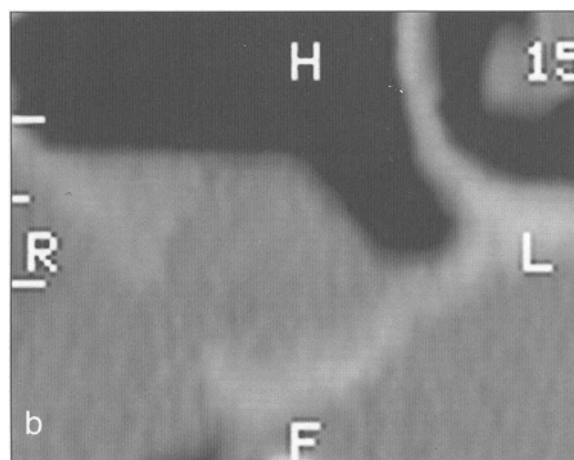
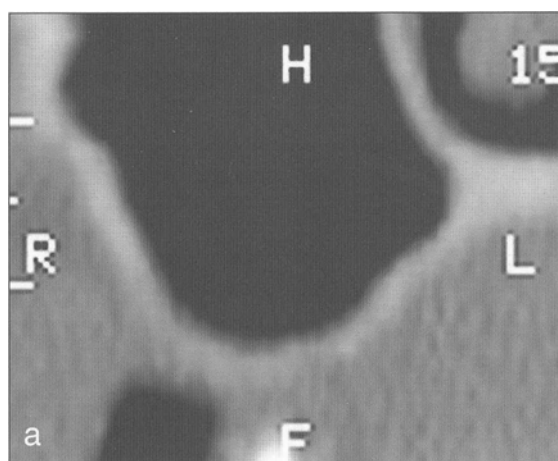


Fig 12-6 Periapical radiographs of patient 401 at baseline and 12 weeks postoperatively, showing remodeling of the cortical border of the antral floor and septum within the maxillary sinus following rhBMP-2/ACS treatment.



Figs 12-7a and 12-7b Computerized tomography sections at baseline and 16 weeks postoperatively for patient 402. The mean height at baseline is 2.03 mm, and the mean height 16 weeks postoperatively is 16.87. The height response is 14.84 mm.

Technical feasibility

Technical feasibility scores indicated that the rhBMP2/ACS device was easy to use. Mean scores ranged from a low of 3.7 for time of preparation to 4.0 for cohesiveness. The median score was 4.0 for all parameters (most favorable).

Measurements of bone induction

Periapical radiographs

Trabecular patterns within the rhBMP-2/ACS treatment area became evident in five, seven, and nine of 12 patients 8, 12, and 16 weeks, respectively, after rhBMP2/ACS implantation. Congruence of the newly induced bone with the underlying native bone of the antral floor was seen in the same proportion of patients at the same time points as the trabecular patterns. Additionally, unplanned qualitative observations suggestive of new bone formation at the rhBMP-2/ACS treatment site were made: (1) remodeling of the cortical border of the antral floor and septum within the maxillary sinus (ie, they were no longer visible) was seen as early as 4 weeks after rhBMP-2/ACS implantation; and (2) increased radiodensity of the rhBMP-2/ACS treatment area was seen 16 weeks postoperatively (Fig 12-6).

Computerized tomographic scans

Evaluable CT scans were available from 11 of the 12 patients. One of the 12 patients could not be included in these analyses because of a mucous retention cyst present at the site of rhBMP-2/ACS implantation, which interfered in the rater's ability to distinguish the superior border of the alveolar ridge. Representative CT scan cross sections (baseline and 16 weeks postoperatively) are presented in Figs 12-7 a and 12- 7b. Table 12-2 lists the average bone height response (16-week alveolar ridge height minus baseline alveolar ridge height) of the two cross-sectional multiplanar reformatted images for each patient as measured by the three raters and the mean height response reported by the three raters, collectively.

The data indicated that there were few differences among the three radiologic raters' bone height response measurements. Overall, rhBMP-2/ACS treatment resulted in a mean bone height response of 8.51 ± 4.13 mm (range of 2.28 to 15.73 mm; 95% CI = 6.07 to 10.95). Because the lower bound of the 95% confidence interval did not include zero, it can be concluded that significant overall bone height growth resulted from the rhBMP-2/ACS treatment.

Table 12-2 Average bone height response using CT scan

Patient	Mean height at baseline (mm)	Mean height at week 16 (mm)	Height response (mm)			
			Mean	Rater 1	Rater 2	Rater 3
JOI	9.40	20.53	11.13	10.50	12.30	10.60
102	5.35	13.70	8.35	8.95	10.05	6.05
JO3	2.35	18.08	15.73	15.20	16.35	15.65
201	2.42	6.15	3.73	3.80	3.10	4.30
202	3.83	10.38	6.55	5.65	6.45	7.55
203	1.63	9.63	8.00	7.75	7.65	8.60
302	9.37	11.65	2.28	3.45	1.10	2.30
303	3.57	9.70	6.14	6.15	6.20	6.06
304	7.98	16.17	8.18	7.70	9.05	7.80
401	1.62	10.28	8.67	8.45	8.50	9.05
402	2.03	16.87	14.83	14.20	15.30	15.00

Five (45%) of 11 patients (95% CI = 17% to 77%) met the optimal bone height criterion for dental implant placement. An additional 27% (3 of 11, 95% CI = 6% to 61 %) met the minimum bone requirement for dental implant placement. Thus, 73% (8 of 11, 95% CI = 39% to 94%) of the patients treated with rhBMP-2/ACS met the definition of adequate bone for the placement of dental implants.

Histologic evaluation

Core bone biopsy specimens were obtained from 11 patients who had endosseous dental implants placed in the rhBMP-2/ACS treatment area (two of the 11 patients did not meet the criteria for adequate bone). Biopsy specimens were obtained from two patients 19 weeks after treatment with rhBMP-2/ACS. A photomicrograph of a histology slide obtained from a 19-week core bone biopsy specimen is shown in Figs 12-8a and 12-8b. The amount and thickness of trabeculae in the newly induced bone were rated as moderate in these biopsy specimens. The amount of woven bone was moderate to large. A moderate-to-large number of ostea blasts and capillaries in the bone marrow was observed in the newly induced bone. One of these patients also had a core bone biopsy specimen obtained from her own native bone at the time of dental implant placement (Figs 12-9a and 12-9b).

Biopsy specimens were taken from the remaining patients 24 to 44 weeks after rhBMP-2/ACS treatment; representative specimens are shown in Figs 12-10 and

12-11. The amount and thickness of the osseous trabecular bone varied from moderate to large, with a highly variable amount of woven bone. Most specimens had a small number of or no active bone cells and a small number of capillaries in the marrow.

No residual collagen matrix was observed in any of the biopsy specimens taken from any of the patients at either the 19-week or 44-week time points.

Implant success

A total of 21 endosseous dental implants were placed in the rhBMP-2/ACS newly induced bone between 19 and 44 weeks after rhBMP-2/ACS treatment. The success of these dental implants as they progress through the osseointegration phase and into functional loading is currently being monitored (Figs 12-12a to 12-12c).

Discussion

The results of this multicenter study provide evidence of the safety and technical feasibility of using rhBMP2/ACS for maxillary sinus floor augmentation and are in agreement with those from earlier animal studies that have indicated that treatment with rhBMP-2 does not result in toxicity, significant immunologic reactions, or other serious adverse effects.⁵⁻⁸ Adverse experiences observed with rhBMP-2 were consistent with the usual morbidity observed in the maxillary sinus floor augmentation procedure.

Figs 12-Ba and 12-Bb Photomicrographs of a histologic specimen for patient 401, taken 19 weeks post-operatively from the rhBMP-2/ACS treatment site.

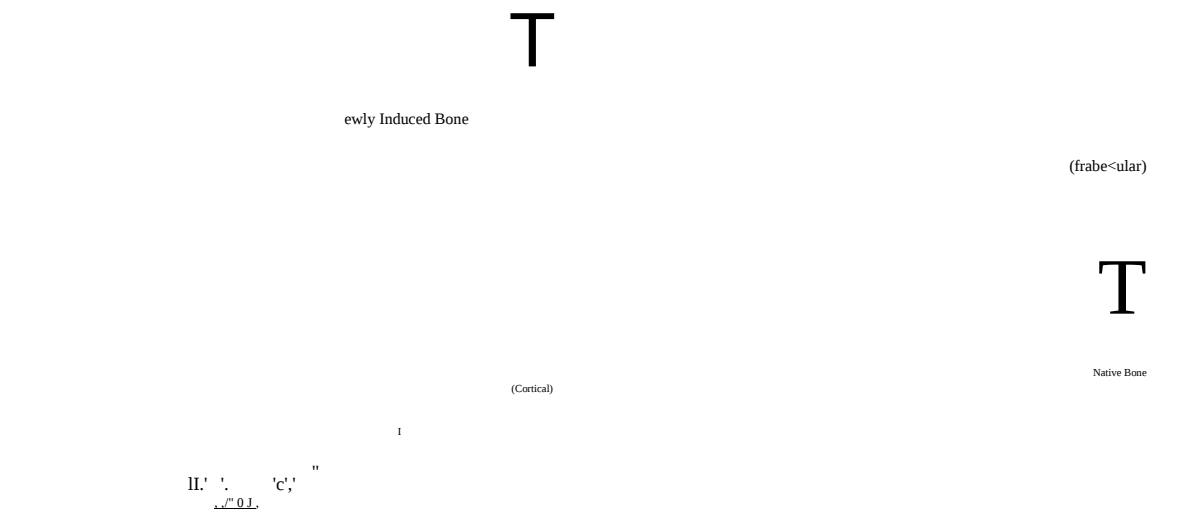


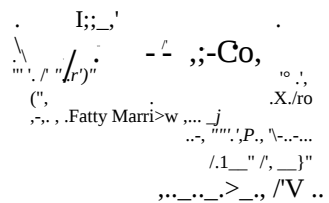
Fig 12-8a Magnification x 1 shows the entire specimen (both native and newly induced bone). For orientation, the coronal end of the specimen was marked with India ink.

Figs 12-9a and 12-9b Photomicrographs of a histologic

S)

Fig 12.8b Magnification x 10 of the newly induced bone shows a vascular specimen with trabeculae consisting of both woven bone (WB) and lamellar bone (LB) surrounded by osteoblasts (OB). (OC) osteoclast.

nen for patient 402, taken from the native bone.



Trabecular
Thickness

Fig 12-9a Magnification x 1 shows the entire

specimen.

Fig 12-9b Magnification x 10 shows trabecular lamellar bone (LB) with fatty marrow.

Figs 12-10a and 12-10b Photomicrographs of a histologic specimen for patient 10], taken 27 weeks postoperatively from the rhBMP-2/ACS treatment site.

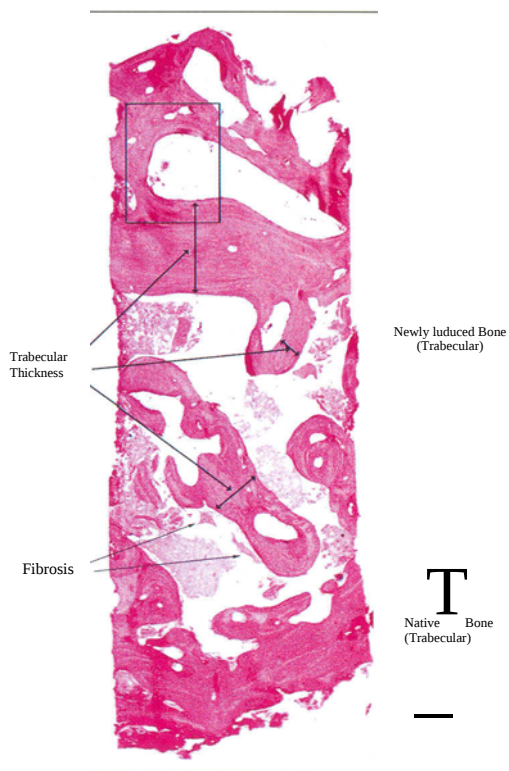


Fig 12-10a Magnification x 1 shows the entire specimen.



Fig 12-10b Magnification x 10 shows mature lamellar bone (LB) and woven bone (WB) with fatty marrow.

Figs 12-11a and 12-11b Photomicrographs of a histologic specimen for patient 302 taken 24 weeks postoperatively from the rhBMP-2/ACS treatment site.

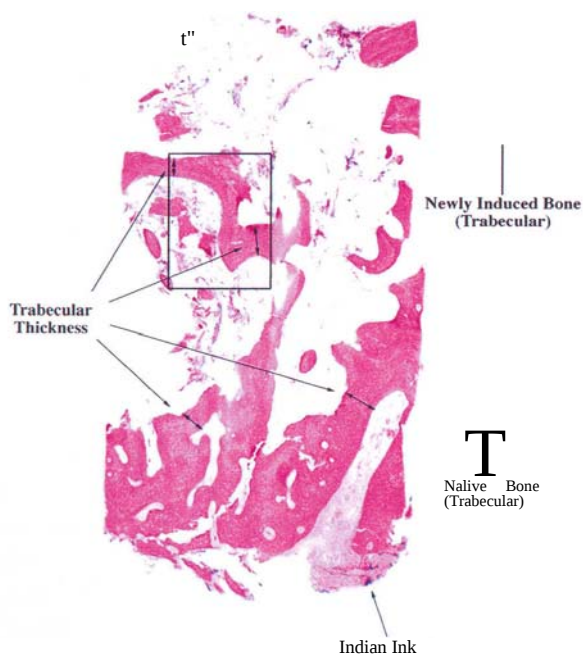


Fig 12-11a Magnification x 1 shows the entire specimen.

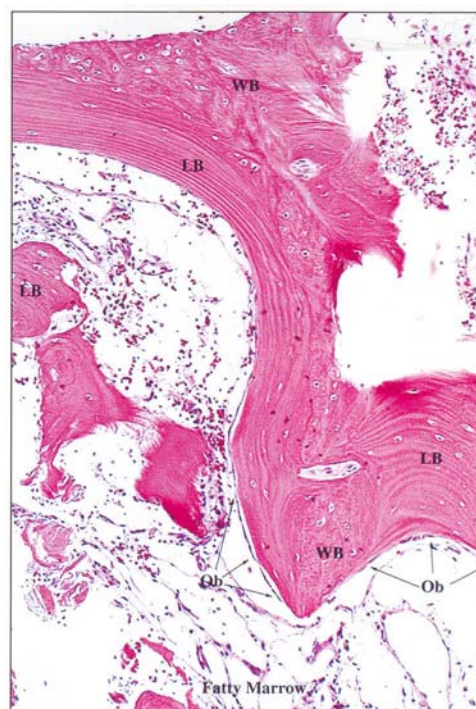
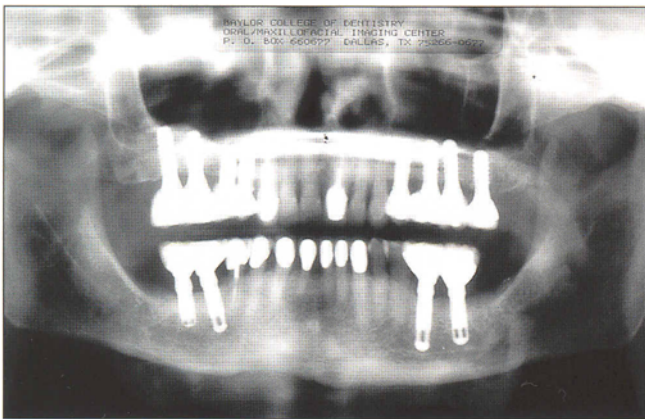
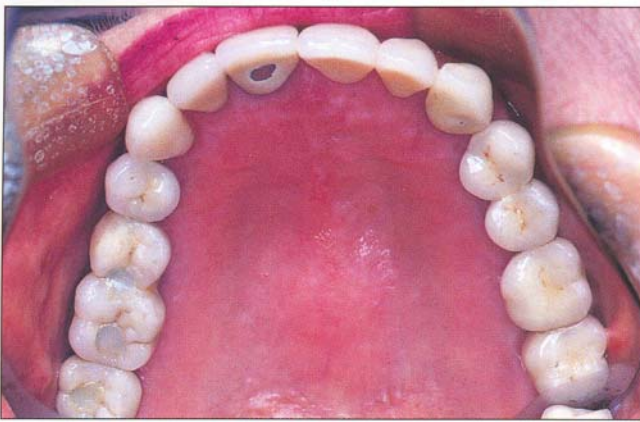


Fig 12-11 b Magnification x 10 shows trabecular bone consisting of both woven bone (WB) and lamellar bone (LB), osteoblasts (OB) along the surface of the trabeculae, and some fatty marrow.



Figs 12-12a to 12-12c Patient 402 completely restored. Right sinus grafted with rhBMP-2j ACS; left sinus grafted with chin autograft.

Problems concerning objective and quantitative assessment of the effects of rhBMP-2/ACS have also been identified in other trials that have used bone-grafting techniques to augment bone along the floor of the maxillary sinus. Clinical judgment has been the primary tool for evaluating the adequacy of augmented bone for dental implant placement, and the timing of these assessments has been largely empirical. As a result, the efficacy of different bone augmentation procedures has not been evaluated separately from studies performed to evaluate the success of functionally loaded dental implants in augmented bone. The data generated from this study suggest that the CT scan is the best radiographic system to reproducibly obtain and measure the dimensions of the newly induced bone.

Radiographic and histologic assessments indicated that rhBMP-2/ACS induced new bone growth in the maxillary sinus floor in 100% of the patients treated, and 8 of 11 (73%) of the study subjects met the criteria for adequate bone for the placement of endosseous dental implants. In experimental animals, tenting and elevation of the sinus membrane with dental implants placed in the alveolar ridge and protruding into the sinus cavity stimulate reactive bone growth that is limited to 1 to 2 mm in height.¹³ This is much less growth than that stimulated by rhBMP-2/ACS in this study. Moreover, studies in experimental animals have shown that rhBMP-2/ACS, but not ACS alone, stimulates new bone growth in the maxillary sinus floor.⁹ The efficacy of rhBMP-2 for inducing osteogenesis is also consistent with findings from a number of other previous preclinical trials.^{5-9,14}

Qualitative evaluation of core bone biopsy specimens confirmed the radiologic demonstration of new bone formation at the sites of rhBMP-2/ACS treatment and suggested that the bone induced by rhBMP-2/ACS remodels and matures during the period between 19 and 24 to 44 weeks after treatment. The specimens taken 19 weeks after treatment generally had more active bone cells and less trabeculae and lamellar bone than did those taken during the later interval.

Conclusion

The potential for bone growth factors in general and rhBMP-2/ACS in particular is exciting for both patients and dental practitioners. Although the release of growth factors for general clinical use seems near, they have not yet been approved for use by the US Food and Drug Administration. This study showed that rhBMP-2/ACS induced bone in this anatomic site in 100% of the patients, but the amount of bone induced did not meet the optimal criteria in the majority of the patients. Additional work remains for both the basic and clinical scientist to determine the ideal therapeutic dose and carrier.

Acknowledgments

The study described in this chapter was previously published in *The International Journal of Periodontics and Restorative Dentistry*: Boyne PJ, Marx RE, Nevins M, Triplett G, Lazaro E, Lilly L, Alder M, Nummikoski P. A feasibility study evaluating rhBMP-2/Absorbable collagen sponge for maxillary sinus floor augmentation (1997;17:11-25). Special thanks to X. Jian Li, MD, Principal Scientist, Head of Histopathology Laboratory, Genetics Institute, for his assistance in evaluating the histology from this study and producing the photomicrographs.

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Prosthetic Management of the Sinus Graft Case

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The relationship of pretreatment prosthodontics to a favorable prognosis requires a team approach between the prosthodontist, surgeon, and dental technician. Each member of this team should understand the long-term goals of treatment. The prosthodontist should be the director of this team, since implant placement depends on the planned subsequent prosthesis.

Assessment and Treatment Planning

Prosthodontic procedures are necessary prior to placement of endosseous root-form implants and sinus augmentation surgery. At the initial patient interview, the prosthodontist should discuss with the patient his or her treatment goals in terms of esthetics and function. If the patient reports that he or she is a smoker, it becomes necessary to explain that these are risk factors that can contribute to implant failure. Ideal treatment goals should be explained to the patient, with reference to either removable or implant-supported fixed-detachable prostheses, as well as the risks and benefits of various treatment modalities, which may include non treatment. An assessment of the patient's expectations and his or her ability to undergo an extended treatment modality are elicited at this interview.

A complete set of right-angled radiographs, a panoramic radiograph, and a reformatted computerized tomography (CT) scan of the maxilla are taken fol-

lowed by a clinical examination of the prospective patient. All of these should be part of the patient's permanent chart.

Maxillary and mandibular diagnostic casts are made and mounted on an articulator using verified maxillomandibular recordings. These casts are duplicated and mounted, and a diagnostic waxup of the anticipated outcome is created. An impression is made from this waxup, and a cast is poured and duplicated. One cast is employed to construct a provisional prosthesis that is used from before first-stage surgery through second-stage surgery. A second cast is used to fabricate a surgical template as an aid for the surgeon to optimally position the implants. Consultation with the surgeon is necessary prior to template construction. This template employs grooves or other markers as guides for the placement of the implants. It also has an open buccal surface to prevent interference with the surgical sinus augmentation procedures.²

During the diagnostic waxup, CT scan evaluation, and surgical template fabrication, the implant team should plan to place one implant per tooth being replaced, either in the sinus graft alone or in conjunction with the residual alveolar bone. No cantilevers should be used.³ The maxillary bone is not as dense as the mandibular parasymphiseal bone, and the torquing stresses from cantilevers during the functional and

parafunctional mandibular movements may cause screw loosening, screw breakage, and unwanted torquing on the implants.

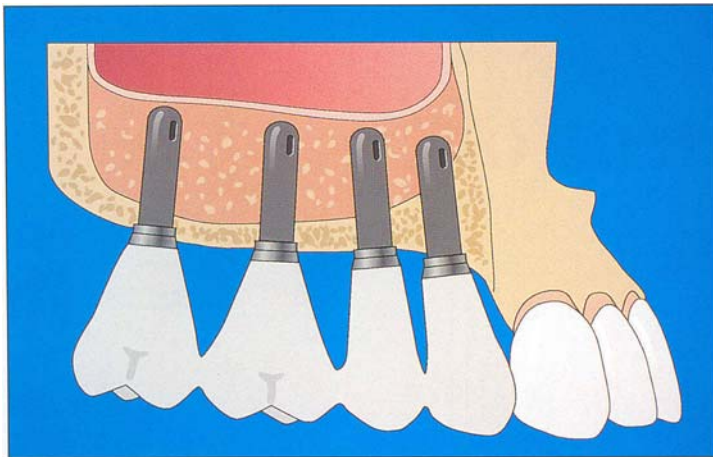


Fig 13-1 Sinus graft where the crown-to-implant ratio is unfavorable. The crowns are longer than the implants.

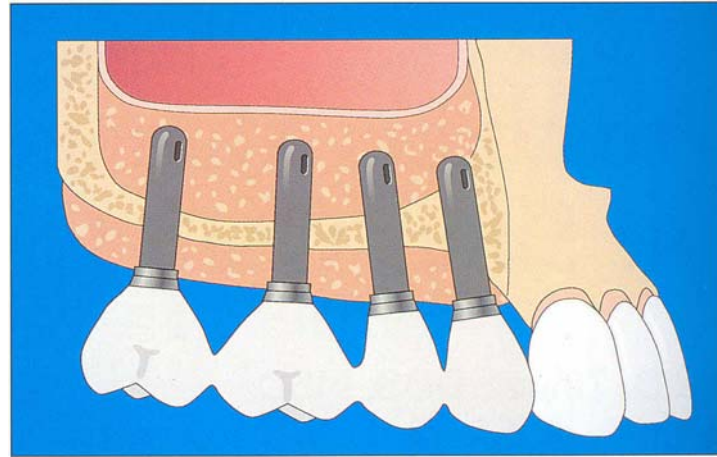


Fig 13-2 Sinus graft with an occlusal bone graft where the crown-to-implant ratio is favorable. The implants are longer than the crowns.

Special Considerations

Buccal bone loss

Anatomic conditions that create prosthetic problems include the loss of the buccal width of the posterior maxillary ridge and/or advanced loss of vertical ridge height. Restoration of either condition through the use of sinus grafts without additional bone augmentation can compromise the prognosis. Loss of the buccal width of the posterior maxillary ridge can result in palatally placed implants and the creation of a buccal cantilever or offset. This occurs when the future implant-supported prosthesis is created with an ideal occlusion and contours for support of the facial musculature and overall esthetics.

One solution to this problem is to recontour the prosthesis, resulting in an inadequate buccal support of the soft tissues and a cross bite occlusal relationship with a narrowing of the dental arch. This may constrict the tongue and result in poor esthetics. Therefore, a better choice is augmentation of the facial portion of the residual ridge with veneer bone grafts in addition to the sinus augmentation. After healing, the implants are placed in their optimal positions. Their positions are those designated from the diagnostic waxup, CT scan evaluation, and subsequent surgical template, prior to grafting and implant placement.

Advanced vertical bone loss

The second difficult anatomic condition is advanced vertical loss of the posterior maxillary ridge. Treatment involves placement of an occlusal bone graft prior to sinus augmentation and implant placement. This is done to avoid an unfavorable crown-to-implant ratio, which may reduce the longevity of the implants and the prosthesis. All prostheses should have a favorable crown-to-implant ratio, similar to the favorable crown-to-root ratio in natural teeth (Figs 13-1 and 13-2). The vertical bone graft placement is again determined from an optimal diagnostic waxup, CT scan, and surgical template guide. After healing, the sinus graft and implant placement surgical procedures are initiated.

Bruxism

The placement of a sinus graft and implants in a patient with severe bruxism is hazardous. According to Jensen,^s who reported the results of the Sinus Graft Consensus Conference at the 1997 Academy of Osseointegration meeting, bruxism is a major cause of implant loss. Management of potential implant recipients who exhibit bruxism involves placing a greater number of implants, which are longer and have wide diameters, as well as allowing a longer healing period between implant placement and uncovering.

The patient wears the screw-retained metal and acrylic resin provisional prosthesis for at least 1 year. The definitive prosthesis should employ a gold framework with acrylic resin veneering to provide shock absorption and a harmonious occlusal scheme. Another method of management is the use of a bar-retained overdenture rather than a fixed-detachable prosthesis.

First-Stage Provisional Prosthesis

Provisional removable partial denture

Transitional removable partial dentures are employed when posterior teeth are missing distal to the canine, whether unilaterally or bilaterally.^{2,6} The removable partial denture is constructed and inserted prior to first-stage surgery. The partial denture should utilize a cast cobalt-chrome alloy metal framework for optimum stability and cross-arch transmission of functional forces. The retentive system should include shallow occlusal or incisal rests as well as retaining and bracing clasp arms.

Extra relief is used over the edentulous ridge areas, in the area of the future surgical section, to permit relief of the acrylic resin denture base. Because this prosthesis is to be worn for at least 9 to 10 months, it should be fabricated from durable materials and allow the alveolar ridge areas to be relined with a soft acrylic resin liner. The transitional removable partial denture is reinserted and lined with one of the tissue treatment soft resin liners 3 weeks following first-stage surgery. The soft liner is replaced every few days after initial insertion until the surgical sites have healed, and then a more durable soft lining is inserted until the time of second-stage surgery.

Pressure from the premature reinsertion of the transitional partial prosthesis may result in implant loss caused by micromovement of the underlying implants as well as pressure on the surgical sites. The patient is informed at the time of case presentation that the provisional removable partial denture cannot be reinserted for 3 weeks; following the placement of the root-form implants and the sinus augmentation procedures. At the time of insertion, no denture flange is retained in the grafted areas.

As was reported at the Sinus Graft Consensus Conference of the Academy of Osseointegration, most of the implants placed in sinus grafts were lost during the first year.^s This may be due to either the premature insertion of a transitional removable partial denture or use of a removable partial prosthesis that does not incorporate a cast-metal framework, which would help to prevent micromovement of the implants and concomitant pressure on the surgical sites. In addition, improper relief of the denture base and use of soft liners may also cause or contribute to these problems. To

avoid loss of the graft and underlying implants, a complete transitional maxillary denture cannot be reinserted until the surgical areas are completely healed.

Fixed provisional prosthesis

When one or more maxillary premolars are present and these are to be eventually restored with complete-coverage restorations, a fixed provisional prosthesis fabricated with a cast-metal reinforcement and heat-cured acrylic resin veneering may be used rather than an interim removable partial denture.⁶ The provisional fixed prosthesis incorporates one or more cantilevered pontics. To reduce torquing on the abutment teeth, pontics used to restore the cosmetic appearance should not be placed in occlusion.

The fixed provisional restoration is reinserted on the day of sinus augmentation and implant placement, because no mucosal load is placed on the surgical sites, as would be the case with a removable partial denture. This restoration allows the patient to return to function and to his or her lifestyle with the least amount of emotional trauma.

Abutment Selection

Usually three or more implants are placed. Preferably, the abutment selected should be conical. This configuration increases the surface area coverage of the gold cylinder over the abutment head to reduce torquing forces. Sufficient inter arch space is needed, and at least 7.5 mm occlusogingival height is required. If less space is available, then a 3-mm-high standard or nonrotational abutment should be selected.

Antirrotational components are preferred. Each gold cylinder is stabilized at the interface with the abutment rather than by the retaining screw alone. This provides a more precise fit between the gold cylinder and abutment. The antirrotational features reduce screw loosening and torquing resulting from the functional and parafunctional forces of occlusion.[?]

Direct connection to the implant^s without an intervening trans epithelial abutment is used only when there is less than 6 mm of interarch space. This is the least desirable of situations, because, if the abutment screw fractures, it is quite difficult to remove. If a gold retaining screw fractures, its replacement is easier.

Second-Stage Provisional Prosthesis

Following second-stage surgery, a screw-retained fixed detachable prosthesis is fabricated.² This restoration is



Fig 13-3 Gingival view of second-stage screw-retained, metal-reinforced, heat-cured acrylic resin provisional prosthesis. Provisional cylinders are manufactured from titanium alloy.

placed as soon as feasible following attachment of the transmucosal abutments (Fig 13-3). The second-stage provisional prosthesis permits incremental loading of the grafting material and surrounding alveolar bone. Slow, incremental loading allows time for the maturation of bone and grafting materials. The grafting material and adjacent maxillary alveolar bone benefit by the remodeling process as a reaction to the stresses transmitted through this gentle loading process. Early implant integration is not very strong, but the progressive loading through the use of a rigid, passively fit, screw-retained, metal-reinforced, acrylic resin-veneered prosthesis aids in the loading required for maturation of the graft and surrounding alveolar bone.

According to Tatum/ the length of time required for progressive loading depends on the type, particle size, and height of the graft and the length of the implants. Mischlo has stated that, "Each step of the progressive loading process is allowed sufficient time for the bone to respond to the increased stimulation. Ideally, woven bone transforms into load bearing lamellar bone, along with an increase in the percentage of bone at the implant interface." Binon and Sullivan¹¹ have stated that "the use of a resilient, shock absorbing acrylic resin provisional restoration limits stress wave and shock transfer to the implant, enhancing the desired gradual trabecular reorientation."

The occlusion on this provisional prosthesis should be fabricated in such a way as to permit loading in a vertical direction while reducing lateral forces, thereby minimizing the unwanted torquing forces transmitted to the implants.

Fabrication technique

Tapered transfer copings are screwed to place in the transmucosal abutments, and a complete-arch reversible hydrocolloid impression is taken. Screw-secured impres-

sion copings and an overall elastomeric impression are not used, because of the sutures placed after secondstage surgery. The elastomeric impression materials could tear the sutures and open the surgical site.

Abutment analogues are screwed on the transfer copings, and a die stone cast is poured. After separation, the maxillary and mandibular casts are mounted to verified maxillomandibular records. Provisional titanium cylinders are selected for the abutments employed and screwed on the abutment brass analogues. The metal cylinders are luted together with acrylic resin, allowed to set on the cast, and tried intra orally to verify the impression. When an inaccuracy is noted, it is corrected intra orally, and then the cast is altered.

The heights of the channels of these interim cylinders are reduced to the correct occlusal relationship. Metal cylinders should contact the opposing dentition at the centric occlusal position. Acid-etched and silanized polyethylene fibers are wrapped around the metal provisional cylinders. Stainless steel wire, a titanium bar, and/or a cast-metal reinforcement are employed to prevent breakage and add rigidity to the acrylic resin provisional prosthesis.

The desired prosthesis is then waxed to optimum form and processed with heat-cured acrylic resin to the selected shade. To avoid flasking and deflasking procedures, which might mar the gingival portions of the metal cylinders, an Ivomat (Ivoclar) heat- and pressurecuring machine is utilized. The use of the Ivomat machine requires construction of stone, plaster, or elastomeric putty facial and palatal indices of the waxup. After set and separation, the wax is boiled off of the cast and cylinders. Separating medium is painted on the gypsum cast and indices. The metal reinforcement is secured in place with autopolymerizing acrylic resin of the selected shade. Monomer and polymer of the selected heat-cured acrylic resin are painted around the cylinders and built up to the required contours, and slightly overbuilt.

When the glossy appearance disappears, the indices are replaced, and the entire assembly is placed into the Ivomat machine and cured. After cooling, the acrylic resin is carved, corrections are made, and any additions of acrylic resin are cured in the Ivomat machine. Finally, the restoration is refined and polished. Acrylic resin that spills into the screw-access channels is removed, and the occlusion is verified.

The restoration is placed in the patient's mouth. The contours, shade, and occlusion are verified, and corrected when necessary, and the prosthesis is repolished. To verify the accuracy of fit, a one-screw test is used. In this method, one screw is inserted and tightened in the most anterior cylinder. At this time, all the provisional cylinders must fit accurately and demonstrate a seating error from the horizontal seat of the other abutment heads. If it does not fit properly, the prosthesis is sectioned, the parts are secured, and the sections are reattached intraorally with autopolymerizing acrylic resin.

Once the resin has set, the restoration is removed, refined, and reinserted. At the time of insertion, the occlusal table should be narrowed, the centric occlusal contacts should be verified, and eccentric contacts should be minimized to avoid torquing forces on the implants and the graft material. Thus this restoration is designed to concentrate the occlusal forces in the vertical direction.

This provisional prosthesis is worn for approximately 6 months to 1 year. When the anterior implant or implants are in the patients' residual alveolar bone and the posterior implants are in the sinus graft, the definitive prosthesis is constructed. This usually occurs approximately 6 months after placement of the second-stage provisional prosthesis. If the prosthesis only includes implants placed in graft material, the provisional restoration is worn for about 1 year prior to fabrication of the definitive prosthesis, to allow time for maturation of the grafting materials.

The second-stage screw-retained provisional prosthesis has the following additional advantages:

1. It acts as a template for the definitive prosthesis.
2. It allows the patient to have a fixed prosthesis after second-stage surgery.
3. It allows the patient to learn to maintain and function with a screw-retained fixed-detachable prosthesis.
4. Patient comfort, function, and esthetics are improved after second-stage surgery. Abutments can be changed and the prosthesis altered after soft tissue healing, if the metal of the abutment mars the esthetics.
5. After completion of the definitive prosthesis, the provisional prosthesis is then retained by the patient and can be used if alterations of the definitive prosthesis are required or if additional implants are added at a later time.

Definitive Prosthesis

Fixed-detachable screw-retained prosthesis

The definitive prosthesis is a fixed-detachable screw-retained restoration, usually constructed from type IV gold alloy with a heat-cured acrylic resin veneer.^{2,6,7} Acrylic resin occlusal surfaces are employed for the resin's shock absorption effect to reduce forces on the underlying graft and implants.¹²⁻¹⁴

The preferred implant design is one that has an external hex head. This allows use of a manufactured abutment with antirotational capacity to be secured to the implant with an abutment screw and facilitates fabrication of a prosthesis retained by a gold retaining screw. The advantage of the gold retaining screw is that, if the system overloads, the gold screw will break rather than torque the implants.

Fabrication technique

Tapered impression copings are screwed to place and either a reversible hydrocolloid or an elastomeric complete-arch impression is taken. Impression copings are removed from the mouth and screwed to the appropriate analogues, and a die stone cast is poured. This is mounted to verified maxillomandibular records.

Prefabricated gold-palladium cylinders are screwed in place on the brass analogues. The use of manufactured gold cylinders ensures optimum fit between the gingival portion of the cylinder and the abutment head, which cannot be achieved with a laboratory cast cylinder made from a plastic pattern. Steel waxing pins are used to secure the gold cylinders in place. Acrylic resin is used to join all the gold cylinders together.

This assembly is tried in the mouth to verify the accuracy of the impression, using one gold screw into the most anterior cylinder. If the gold cylinders do not fit the abutment heads accurately, the resin splint is sectioned, the gold cylinders are screwed to place, and the resin splint is reattached intraorally.

After the acrylic resin has set, the resplinted gold cylinders and resin splint are removed, and the analogues in the master cast are altered to proper position. Waxing pins are shortened to proper occlusal contact, and a new groove is cut for a straight slotted screwdriver. The design of the gold framework includes a high palatal wall short of the occlusal, a short buccal waxup, and a gingival gold finishing line to allow room for the buccal and occlusal acrylic resin veneering material (Fig 13-4). The screw-access channels are waxed into occlusal contact.

The completed waxup is sectioned to allow for individual casting of the waxup of each gold cylinder. Ten-gauge sprues are attached to the lingual surface of



Fig 13-4 Buccal view of waxup for gold alloy and acrylic resin veneered definitive prosthesis.

the waxup. The waxup is invested, cast with a type **IV** gold alloy, and then divested.

The screw-access channels are sandblasted and then cleaned with an E cutter (H 364E.104.023, Brasseler), a safe-ended, straight-fluted milling bur. Steel protection caps are screwed to place before refinement of the castings by rotary instrumentation. These are used to prevent damage to the manufactured gold cylinders. The framework castings should accurately fit the analogues on the cast before they are tried in the patient's mouth.

At the time of intraoral try-in, the parts of the cast prosthesis framework are screwed to place with gold retaining screws. These fit more accurately than the waxing pins, which may have debris on them and may interfere with occlusal adjustment. An intraoral soldering index is taken of the castings. Once set, the entire assembly is removed, invested, and soldered.

After cleaning, the assembled framework is evaluated intra orally by placing one gold retaining screw in the anterior cylinder. At this time, all of the gold cylinders must fit accurately. If there is an error, the assemblage is sectioned where necessary, the parts are screwed to place intra orally, and a soldering index is taken. After setting and removal from the mouth, the parts are invested, soldered, and retried intraorally.

During the soldering procedure, to protect the gold cylinders and screw-access channels, as well as to maintain the parts in place to reduce movement, brass analogues are secured with new long steel waxing pins. Then the index, with the prosthesis, steel pins, and analogues, is invested for soldering. In addition, as a check on the accuracy of the soldering, prior to investment and securing of the parts, a soldering index cast is created. This is made by fixing analogues to the gold cylinders with gold screws after removal of the framework from the mouth. Fast-setting die stone is mixed and placed in a small plastic form or box, and the frame

work, with the soldering index and analogue, is placed in the box. Only the analogues are placed in the stone. Once the stone is set, the gold screws are removed, and the assembly is removed from the analogues.

The indexed framework is invested and soldered. After soldering and divesting, the assembly is tried onto the soldering cast for accuracy of fit. If fit is verified, it is then tried intraorally. If fit is not accurate, the prosthesis is sectioned, fitted to the soldering cast, indexed, invested, and resoldered.

Once the fit is approved on the cast, the prosthesis is retried intra orally. The centric occlusal contacts and contours of the restoration are evaluated. The gold screws are removed and steel waxing pins are inserted in each screw-access channel. A plastic complete-arch impression tray is selected, and a window is cut out over the area of the waxing pins. An elastomeric impression is taken, the steel pins are unscrewed, and the impression and prosthesis are removed from the mouth.

Analogues are screwed to the gold cylinders, and silicone soft tissue casting material is syringed around the gingival area of the prosthesis. The impression is then boxed and poured. After it has set, the cast is mounted on the articulator to verified maxillomandibular records. The gold framework is refined and polished, and occlusal contacts are verified (Figs 13-5 to 13-8). The acrylic resin veneering is then processed and the occlusion refined (Figs 13-9 to 13-11).

When root-form implants are placed in a sinus augmentation graft, lateral torquing functional and para-functional forces on the prosthesis should be kept to a minimum. This may be achieved by creating a favorable occlusal scheme, using the shock-absorbing capability of heat-cured acrylic resin. A narrowed occlusal table, concentration of vertical centric occlusal contacts, diminution of lateral forces, and elimination of cantilevers provides additional parameters for success. The harmonious occlusal scheme, both intra-arch and interarch, is needed for favorable long-term use.

Alternative fabrication techniques

Acrylic resin-porcelain veneers

An alternative method of creating the definitive prosthesis uses multiple-unit gold cylinders with a combination of acrylic resin and porcelain veneers.¹⁶ The positions of the gold cylinders are verified intraorally. The framework is waxed with an occlusal ridge between the screw-access channels and the buccal veneer (Figs 13-12 and 13-13). Mechanical retention is added occlusally and palatally. The retention terminates at the occlusal ridge.

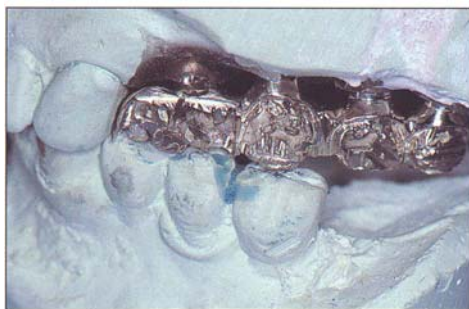


Fig 13-5 Buccal view of assembled type IV gold alloy framework on mounted casts after intraoral evaluation and prior to completion.



Fig 13-6 Palatal view of assembled type IV gold alloy framework on cast following intraoral try-in. Note the high palatal wall short of the occlusal surface, which is needed to prevent flexion of the prosthesis.



Fig 13-7 Buccal view of polished framework prior to veneering with heat-cured acrylic resin. Steel protection caps and/or analogues are used to protect the seating surfaces of the gold-palladium cylinders. The gingivobuccal finishing line is undercut for additional acrylic resin mechanical retention.



Fig 13-8 Palatal view of polished framework prior to veneering with heat-cured acrylic resin. Steel protection caps and/or analogues are used to protect the seating surfaces of the gold-palladium cylinders.



Fig 13-9 Gingival view of completed prosthesis. Gold alloy, not resin, faces the gingival tissues. Use of the Iv om at heat and pressure machine rather than flask investing and divesting for processing the heatcured acrylic resin veneer prevents inadvertent injury to the gold-palladium cylinders.



Fig 13-10 Occlusal view of completed prosthesis. The gold screw-access channels are in contact with the opposing occlusal surfaces.

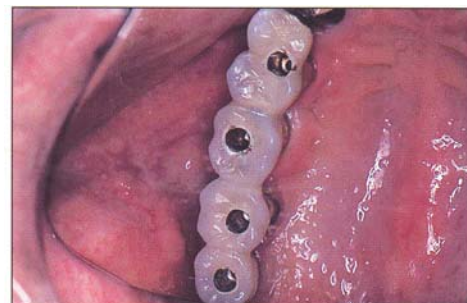


Fig 13-11 Intraoral view of completed screw-retained gold and acrylic resin veneered definitive prosthesis.



Fig 13-12 Buccal view of wax up for porcelain veneering.



Fig 13-13 Occlusal view of waxup for occlusal and palatal heatcured acrylic resin veneering in conjunction with buccal porcelain veneers. White occlusobuccal strut of wax is the delineation between porcelain and acrylic resin.



Fig 13-14 Occlusal view of ceramometal castings fitted to the soft tissue cast. Each implant casting has been cast and fitted separately. Intraoral soldering indices are used for assemblage.



Fig 13-15 Buccal view of assembled ceramometal prosthesis on the soft tissue cast. Metal used is a 52% gold and palladium alloy without silver.

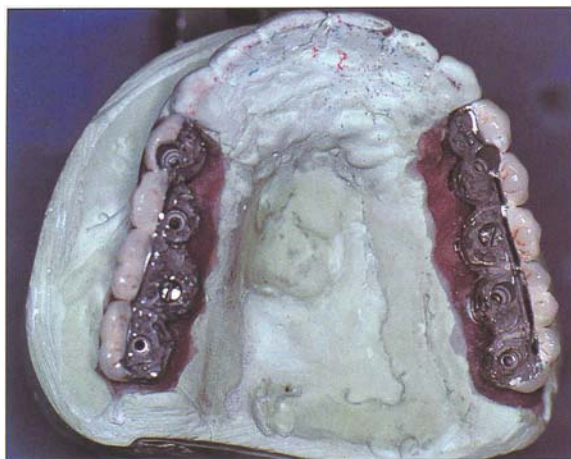


Fig 13-16 Occlusal view of maxillary soft tissue cast with bilateral posterior ceramometal sinus graft prostheses, following intraoral evaluation of assemblage and baking of the buccal porcelain veneers.



Fig 13-17 Completed screw-retained prosthesis after processing occlusal and palatal heat-cured acrylic resin veneering. Gold screw-access channels contact the opposing dentition. Occlusobuccal metal delineates the buccal porcelain veneers from the occlusal acrylic resin.

The waxup is sectioned, sprued, and invested with a phosphate-bonded investment. The castings are made of a gold-palladium alloy. After cooling, the castings are divested and fitted to the cast (Fig 13-14). They are tried intraorally and a solder index is secured. A soldering cast is made as described earlier. The castings are invested and soldered with the appropriate ceramometal solder. The framework is tried intraorally using the one-screw test. If the fit is accurate, then a second complete-arch impression is made and a soft tissue cast is poured (Fig 13-15).

The portion of the casting facial to the occlusal ridge of gold is baked with porcelain veneering of the chosen shade (Fig 13-16). This is evaluated intra orally for contour, shade, and facial appearance. The occlusal contacts are verified, and the occlusal and palatal surfaces are cured in heat-cured acrylic resin of the same shade in the Ivomat heat and pressure machine (Fig 13-17). This technique uses acrylic resin occlusally for shock absorption while it provides an optimum esthetic result.

Porcelain-fused-to-gold materials

A third method for fabrication of a screw-retained fixed prosthesis employs porcelain-fused-to-gold materials.¹⁸ Multiple-unit gold cylinders are used to overcome distortions of metal during the baking of the porcelain veneers. Problems can result from the increased impact forces generated by the porcelain veneering material. No long-term studies of the use of this material to restore an implant placed in a sinus graft have been published.

Removable bar prosthesis

An additional method for a completely edentulous maxilla utilizes a removable bar type of definitive prosthesis.¹⁹⁻²¹ This is employed to improve patient hygiene, especially when there is advanced anterior maxillary alveolar bone resorption. If the anterior portion is al

lowed to remain without implants because of the advanced alveolar bone resorption, the removable appliance will reduce the stress on the graft and the implants and improve the esthetic result.

Either a Dolder bar or a round Ackermann bar is usually employed. If the length and width of the implants placed into the sinus grafts are sufficient and at least six are in place, a spark-erosion-type of removable bar prosthesis can be constructed. This is less resilient and tissue borne than the other types of bar prostheses.

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Load Factor Analysis for Implants in the Resorbed Posterior Maxilla

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The long-term success of osseointegrated screwshaped titanium implants seems to be governed by the degree of anchorage and implant stability achieved during surgery and the initial healing period! and by the type and magnitude of loads that are acting on the implants during masticatory function.² Thus, a balance between implant anchorage and functional loads has to be considered when an implant case is planned.

The loss of teeth normally leads to atrophy of the remaining alveolar bone with time; in the maxilla, this takes place in both the vertical and buccopalatal directions.³ In the severely resorbed maxilla, the implants will be placed more palatally and superiorly than the lost natural teeth. This will result in an unfavorable loading situation in which prosthetic cantilevers and bending forces act on the implants. Furthermore, the resorptive process, in combination with the presence of the maxillary sinuses and the cavity of the nose, results in small bone quantities. It is also known that maxillary bone is less dense than mandibular bone.⁴ This means that implant treatment of the resorbed maxilla is delicate, because both the anchorage and loading situations are far from optimal.

To ensure successful treatment in such cases, a number of modifications could be considered: limiting the occlusal forces; eliminating prosthesis leverage; placing a sufficient number of implants and optimizing their position; selecting the best sites available for primary bone anchorage; and relying on regeneration of bone over time for sufficient secondary stability. To incorporate these parameters into the treatment planning, a

checklist technique could be used. This chapter describes such a procedure, adapted to the posterior partially edentulous segment in the maxilla, and addresses the function of a graft from this aspect.

Biomechanical Parameters for Implants in the Posterior Segment

Bone support

The overall degree of implant anchorage is determined by the bone quality and volume.^{6,7} If a large portion of the implant surface is initially engaging and facing dense cortical bone, it is likely that the capacity of transferring loads to the surrounding bone structures is already high after implant placement. Most posterior maxillae have little cortical bone,⁴ and, therefore, little of the implant will engage cortical bone after placement. However, the healing process and formation of bone will result in an increased degree of bone-implant contact, increased implant stability, and an increased capacity for conveying loads to the surrounding bone.⁸

Empirically, 6 months seems to be a sufficient healing period for most maxillary implants. However, from a biologic point of view, it is possible that the implants may gain in stability for 18 months or even longer, in accordance with the time needed for bone repair.⁹ Based on clinical experience,¹⁰ extended healing periods may be called for in the posterior maxilla, and surgical techniques should be directed to careful site preparation;

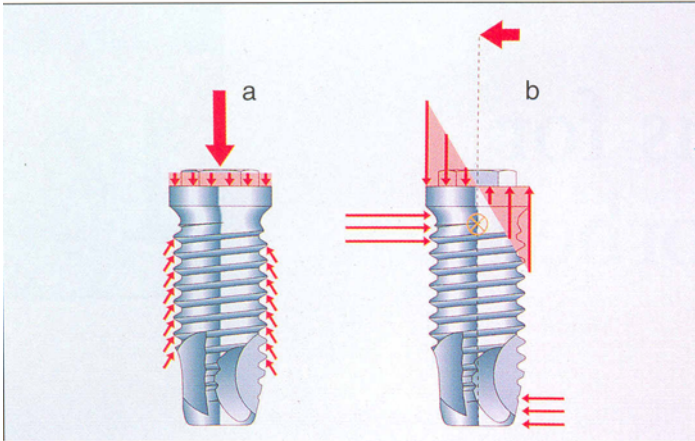


Fig 14-1 Axial load (a) places low stress on the mechanical and biological parts of the implant, while bending (b) increases stress on both implant body and bone. (From Rangert et al.⁵)

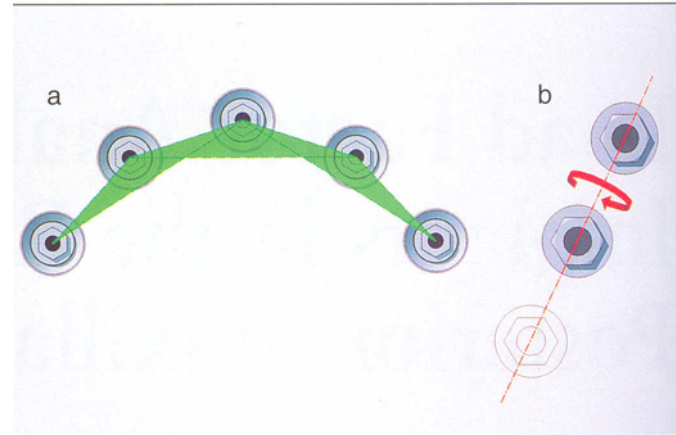


Fig 14-2 The complete-arch restoration (a) allows axial forces to counteract bending because of its inherent cross-arch stabilization, in contrast to the short-span restoration (b), in which the in-line placement subjects the implants to a bending moment when the prosthesis is loaded in the lateral direction. (From Rangert et al.⁵)

ways of preserving and utilizing dense bone structures for mechanical anchorage are deemed important. Also methods of bone compaction and bone grafting have been suggested and utilized.¹¹ In all these situations, allowing healing time for the bone to form and remodel to sufficient secondary stability is critical for a predictable result.

Axial force versus bending moment

In the edentulous maxilla, cross-arch stabilization, obtained by placement of implants along the curved line defined by the alveolar ridge, allows axial implant forces to counteract lateral contacts. For the short-span prosthesis with a typical in-line placement of the implants, however, this kind of support is not at hand, making the restoration susceptible to implant bending⁵ (Fig 14-1). The implants in the complete-arch restoration thus, from a civil engineering point of view, can be considered to have been placed in an optimal way to withstand loads during function, while the implants in the short-span posterior prosthesis are primarily placed as tooth root substitutes, because they will gain less support from each other (Fig 14-2).

Mixing implants and teeth

Because the short-span implant-supported restoration will function together with teeth, both flexible and rigid segments are mixed in the same quadrant. Teeth, suspended by the periodontal ligament, are, in contrast to implants, flexible and also movable if an orthodontic load is applied. Divergence in load distribution between these different segments has added a new dimension to

the treatment-planning process,¹² and the rigid implants may be subjected to a larger percentage of the masticatory forces than the teeth. The wear of teeth in these situations may also lead to an increase of load to the implants. This situation is in contrast to the complete-arch situation, where the relative position of the prosthetic teeth is controlled by the rigidity of the prosthetic structure and, therefore, a protective occlusal scheme can more easily be maintained (Fig 14-3).

Load factors

Theoretical calculations of load distribution on partial prostheses have demonstrated load increases from cantilevers, offset implants, and cuspal inclination.¹³⁻¹⁵ These analyses, as well as studies on partially dentate patients¹⁶⁻¹⁸ and investigations on implant fractures¹⁹ have confirmed earlier, more empirically defined overload factors—too few implants, adverse effects of cantilevers for the short-span prosthesis, and elevated occlusal forces and weaker bone in posterior regions.

These different means of load increase often act independently of each other and are, therefore, all adding to the load level. A proper name for such parameters could be *load factors*. *Geometric load factors* include the number of implants, their relative positions, and the geometry of the prosthesis. *Occlusal load factors* include lateral occlusal force components and parafunctional habits. The load level defined by these two groups of factors should be weighted against *bone support capacity*, including implant anchorage and adjacent supportive bone structure, and *technological risk factors*, such as mechanical strength of components and prosthesis precision (Fig 14-4).

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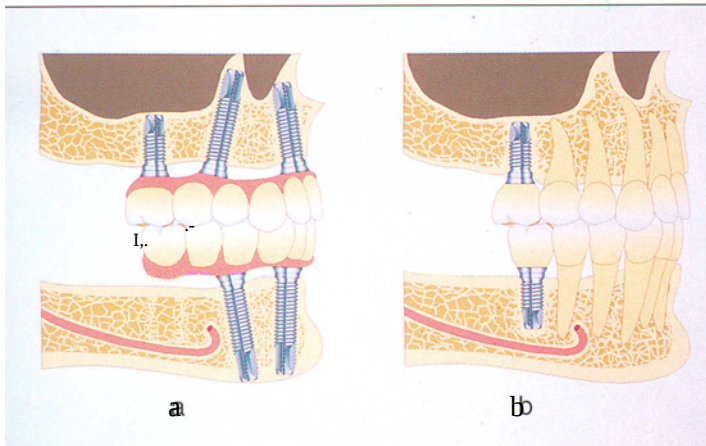


Fig 14-3 In the complete-arch restoration, the teeth are fixed relative to each other (a), unlike situations in which natural teeth and implants are mixed (b). The stiffer implants in the mixed situations may be subjected to a major share of the occlusal load. (From Rangert et al.5)

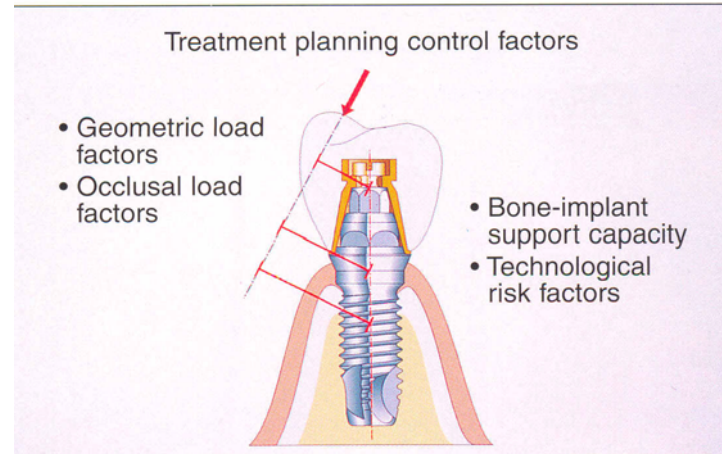


Fig 14-4 Different groups of load factors should be related to the load capacity of the bone and implant and the mechanical components. (From Rangert et al.5)

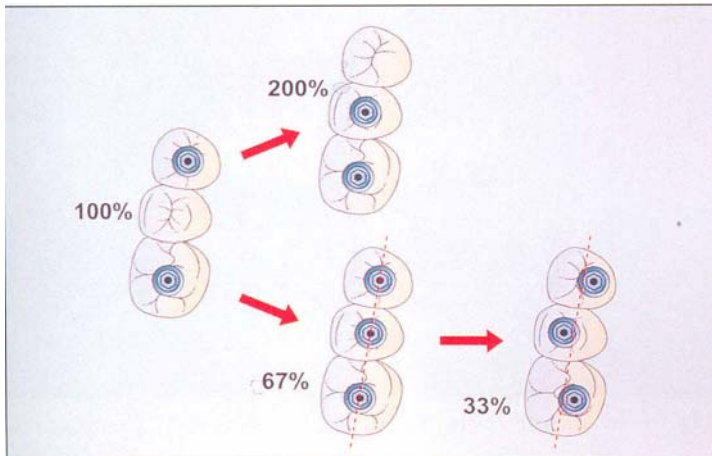


Fig 14-5 The load on an individual implant could vary several hundred percent because of the number of implants, their position, and the prosthetic design. (From Rangert et al.5)

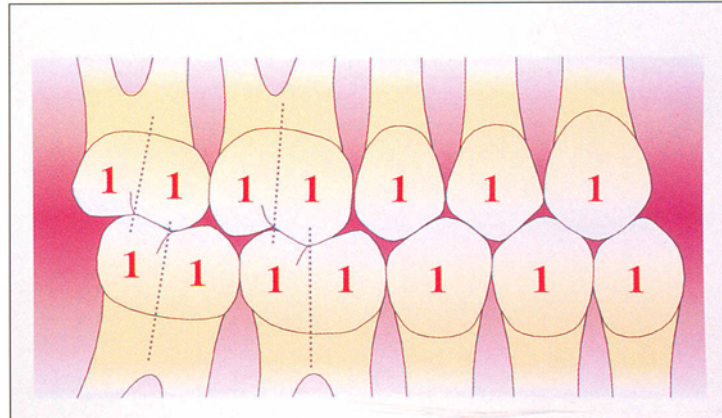


Fig 14-6 Support values of natural teeth. (From Rangert et al.5)

Geometric load factors

The number and position of the implants define the geometric support capacity for a prosthesis. As demonstrated in Fig 14-5, the same prosthesis with the same occlusal load may exert entirely different stress levels on the implants and the supporting bone, depending on the number of implants and the configuration in which they are placed. The cantilever effect exemplified is based on static force calculation, supported by in vivo measurements and the staggering effect is analyzed by calculation models and in vitro measurements. All these factors are determined at the time of implant placement and are, therefore, to a large extent, controllable at the planning stage. Different geometric load factors may include reduced support value; connection to teeth; implants placed in line; and prosthesis cantilevers.

Reduced support value. The lost support of the natural dentition, which is going to be replaced by the implants, can be described schematically according to Fig 14-6. Each loss of a tooth root means the loss of one support. Identifying the support value by these numbers and comparing it to the number of implants placed will give a ranking of the prosthesis foundation.

The advantage of implant placement in an arch configuration is not possible with fewer than three implants. If one molar and a premolar are to be restored, the maximum number of implants that can be accommodated is three. In the case of two premolars or a single molar, the maximum number is two. Therefore, if the support value is three or less, the number of implants ideally should be equal to the support value. If this is not the situation, the implant support is less favorable than that of the replaced dentition, and a load factor is present.

Figs 14-7a to 14-7d For larger restorations, the implants may be placed in an arch configuration. The ideal minimum number is three to utilize the staggering effect.



Fig 14-7a Bone condition before grafting.

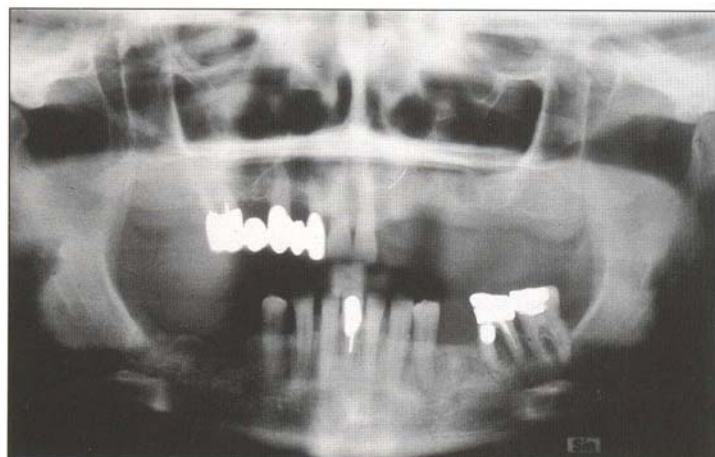


Fig 14-7b Alveolar arch available for implant placement.



Fig 14-7c Implants placed in the graft.

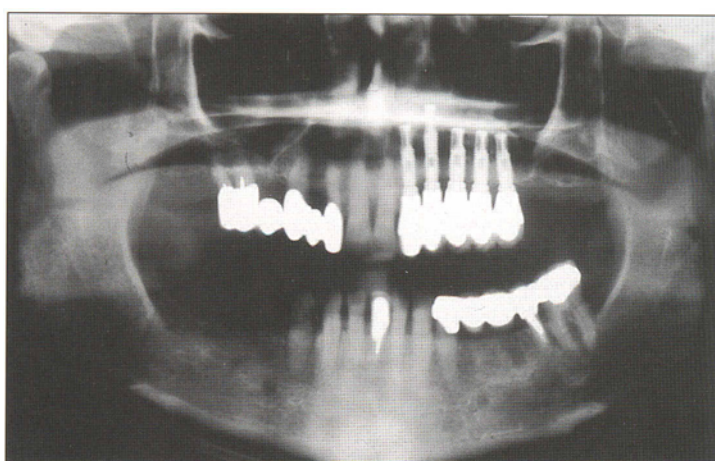


Fig 14-7d Implants positioned along the alveolar arch.

For larger restorations, the placement of three implants is the ideal minimum number. Combined with a curvature following the alveolar arch form, this situation begins to mimic the complete-arch implant prosthesis in load distribution and cross-arch stabilization (Figs 14-7a to 14-7d). Therefore, if the lost support value is four or more, a load factor is at hand if the number of implants is fewer than three.

Connection to teeth. The connection of teeth and implants, with deviating support mobility, makes it difficult to assure a proper load balance between the supports. Therefore, this situation encompasses a geometric load factor.¹⁹ All other geometric load factors, if present, are to be added separately. Especially in the situation of multiple implants connected to teeth, the connecting pontics should be considered as extensions of the implant unit, because the tooth in this situation will most often not participate in the support due to its mobility¹⁹ and its tendency to intrude.²²

Implants placed in line. If the implants are placed along a straight line and the prosthesis is subjected to lateral bending, the implants would react with bending rather than axial forces, with elevated stresses as a consequence (see Figs 14-1 and 14-2). The bending moment on a three-implant restoration, however, can be reduced 20% to 60% if an offset of 2 to 3 mm is used between the implants²¹ (Fig 14-8b). Therefore, in-line implant placement leads to a load factor risk. The one-implant restoration may bend in any direction, and a two-implant-supported restoration, by definition, gives an axis of rotation. Therefore, these situations imply automatic load factors.

Prosthesis leverage. Mesiodistal cantilever extension; buccolingual occlusal extension in relation to the implant position; and excessive height of the crown-abutment complex may increase the implant load by leverage. Cantilevers have greater impact in the partially edentulous situation than in complete-arch situa



Fig 14-8a The resorbed maxilla restored by implants may automatically incorporate prosthesis leverage because of the more palatal and superior placement of the implants.



Fig 14-8b If the implants are placed in a tripod, the support stability is increased.

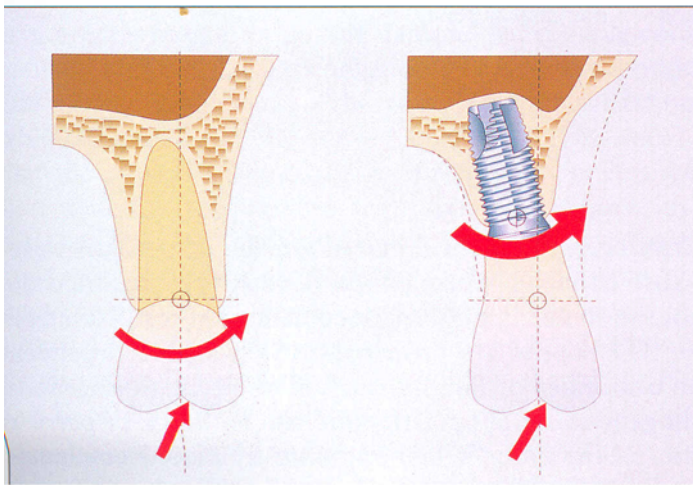


Fig 14-9 The resorbed maxilla restored by implants may automatically incorporate prosthesis leverage because of the more palatal and superior placement of the implants.

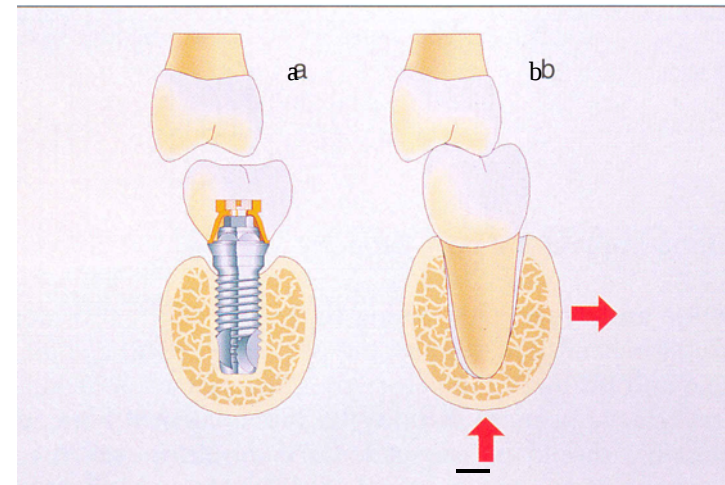


Fig 14-10 Ideally, the contact to the implant-supported prosthesis (a) should be adjusted for the mobility of the adjacent teeth (b). (From Rangert et al. 5)

tions and should not be accepted as a routine arrangement in the posterior segment.⁵ The resorbed maxilla restored by implants may automatically incorporate prosthesis leverage because of the more palatal and superior placement of the implants (Figs 14-8a and 14-9). All these factors will individually increase the stress and add to other load factors.

Occlusal load factors

Evaluation of the primary reason for the loss of the natural teeth may be an effective way of understanding the occlusal conditions of a patient. The force magnitudes during mastication and parafunctional activities each have a proportional impact on the implant load; if these forces are increased above normal, the implant will be subjected to a correspondingly higher load. A history of bruxism and/or broken teeth, as well as obvious signs of tooth wear related to heavy occlusal forces, are, therefore, indicators of a load factor risk.

If hard contact on an implant is allowed during excursive movements of the jaw, the bending load limit of the implant may be surpassed; in the resorbed posterior maxilla, bone resistance may be the limiting factor. Use of different ways to assure that the load is favorably distributed between implants and any natural teeth-as function allows-is therefore important to minimize or completely remove the risk that the stiffer implants will bear a disproportionately high percentage of the total load. Ideally, contact on the implant-supported prosthesis should be adjusted for the mobility of the adjacent teeth by means of centered contacts, flattened cusps, and reduction of the size of the occlusal table (Fig 1410). If this lateral force component is not controlled, this situation should be designated a load factor. Because occlusion may change over time, it is important to check these parameters during the follow-up care in situations where other load factors are present.

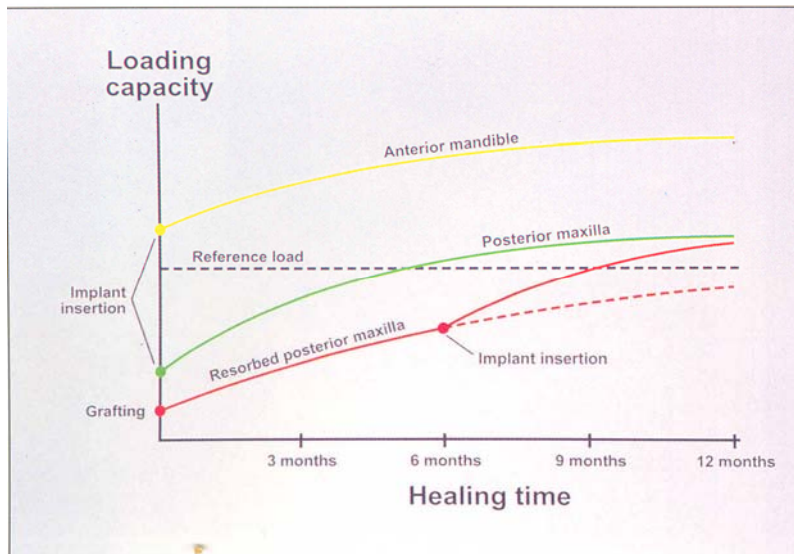


Fig 14-11 To develop sufficient mechanical strength, a graft may need up to 12 months of maturation, and the anchorage still may be inferior to that in dense mandibular bone.

Bone-implant support capacity

Bone anchorage and healing time. Aspects to consider for sufficient bone support are primary cortical anchorage and healing time before the implants are loaded.^{6,7} To achieve primary stability, as much cortical bone as possible should be engaged. Care should be taken to preserve outer cortex for thread anchorage by using minimal or no countersinking.^{1°} Bicortical anchorage should be utilized by engagement of the floors of the nose and maxillary sinus. Pretapping should be avoided, and bone compression techniques may be applied, for instance by using small drill diameters and/or wider implants.

Research indicates that the cortical bone not only provides a good primary mechanical anchorage but also seems to be the most important source for the formation of new supportive bone.⁷ At implant placement, the supportive properties are partly reduced but will be regained during healing and repair of the prepared implant site. This consideration encourages the use of implant diameters and lengths selected for close contact to dense bone structures.^{7,23,24}

After surgery, it is important to evaluate the quality of each implant anchorage,⁴ because all implants are of strategic importance for a posterior partial restoration; if one implant fails, the remaining implants are at increased risk for overload. Extending the healing time or protecting the implant from full loading during the early period in function are two ways to cope with this situation. The dependence on newly formed bone in the absence of good primary stability may be considered a load factor during the early loading period.

Grafting. The use of different grafting techniques to increase the load-bearing capacity has been reported on, but the clinical long-term documentation is still limited.²⁵

The supportive properties of a graft are dependent on a number of factors, such as the type (autogenous, allogeneous, or alloplastic) and shape (block or particulate) of the graft. When implants are placed simultaneously with a bone graft, the graft itself may or may not contribute to primary stability. The use of blocks of grafted bone is likely to improve primary stability, while particulate bone grafts give less or no support. Achievement of secondary stability by healing is delayed in the graft, and it is likely that the early function of simultaneously placed implants is essentially dependent on the stability achieved in the residual basal bone.

From a biologic point of view, a two-stage grafting procedure is preferable⁶ because time will be allotted for revascularization and incorporation before the implants are placed. In this way, the bone graft can respond to the surgical trauma by an initiation of a repair process around the implants, similar to the situation in normal bone.

The time span for these processes is presently not known, but it may take up to several years to reach an optimal support⁷ (Fig 14-11).

Esthetic considerations. In the canine area, depending on the lip line, optimal esthetics also should be considered. Deep placement of implants for optimal esthetics is of high priority, but, for implant stability, it is important that the cortical layer be used for providing initial stability.

The tripod positioning of the implants may sometimes lead to an esthetic compromise, because the buccal inclination of one of the implants to break the in-line placement may lead to perforations of buccal surfaces of the prosthesis, which may jeopardize the esthetic result. In the planning process, use of surgical stents and the use of angulated abutments should be considered to overcome this problem.

Technological risk factors

Technological factors encompass a lack of prosthesis-implant precision and a lack of screw retention of the suprastructure. These factors are not always evident and may add to other factors without any clear notice. Because each implant in a posterior partial restoration is of great strategic value, the demand for reliable components and handling techniques may be more important in this case than in the complete-arch situation, which seems to include some redundancy. This means that the clinician should strive for the best of impression materials, impression tray material designs, and material for casts and investment. In partially edentulous cases it is also more common to restore the patients with metal-ceramic prostheses; because the addition of ceramic material always means distortion of the fit to the framework, it is important that these factors be taken into consideration.

The use of provisional prostheses may allow the evaluation of esthetics, oral hygiene, loading condition, and occlusion. The provisional material per se does not reduce the load, but the design of the provisional prostheses may eliminate cantilevers, minimize width, and flatten cusps to achieve a protection of the implants during the healing and remodeling phase.

Acceptable Load Factors

Use of the checklists in Fig 14-12 is a simple way to assess the load and risk factors to gain an overview of the situation. There are many ways of judging the importance of these factors, but extra caution is called for in the following situations for a partial posterior prosthesis:

- One significant factor, especially heavy bruxism or extremely weak bone
- Two geometric load factors plus occlusal, bone, or technological factors
- Three or more geometric load factors

It should be emphasized, however, that, because implant treatment is multifaceted, an arithmetic expression alone is not an adequate basis for final decision making.

It may be that just one significant factor is enough to jeopardize the result, just as a number of load factors of smaller magnitude may be acceptable. It is up to the skill of the clinician to make the final determination based on the relative significance of the load factors that may be present. The most important part of the screening for load factors is for the clinician to systematically assess and evaluate the different possible factors early, preferably before implant placement, as well as to check what situation is achieved after surgery and adapt the treatment protocol to the conditions present.

It is important to consider all factors of the treatment for a proper evaluation. A weakness in one aspect may be sufficiently compensated for by a strengthening of another. The possibility to actively control the occlusal conditions in situations with multiple geometric load factors seems to be especially significant.

Geometric load factors

- Number of implants less than support value ($SV \leq 3$)
- Fewer than three implants ($SV \geq 4$)
- Implants connected to natural teeth
- Implants in a line
- Cantilever extension
- Occlusal plane aside implant heads
- Excessive height of crown-abutment complex

Occlusal load factors

- Teeth broken as a result of occlusal factors
- History of bruxism
- Implant prosthesis contacting in excursive movements

Bone-implant support capacity

- Dependence primarily on newly formed bone in the absence of good initial stability
- Implant load capacity

Technological risk factors

- Precision
- Screw retention

Fig 14-12 Risk control factors for implants in the posterior partially edentulous segment. 5

Reassessment at follow-up appointments

It is always wise to take action when a patient begins to show signs of overload. The principle for review should be that each implant is of equal significance in the posterior partial restoration. If a screw joint shows a tendency to be unstable by repeated loosening, there is a reason. It might be that the screw is not correctly tightened or that there is a lack of prosthetic precision. If examination confirms a proper screw junction, there is almost certainly an overload situation, and the reason must be determined.

Consequently, it is important to react to mechanical problems, as well as excessive bone resorption, with an appropriate response when they occur. Eliminating cantilevers, narrowing the buccolingual width or mesiodistal length of the teeth, flattening cuspal inclination, and centering the occlusal contact—as well as considering the addition of extra implants and subsequently remaking the restoration—may individually or collectively constitute appropriate action in certain situations.

Examples of Treatment Planning Based on Load Factor Control

The suggested schemes for treatment planning and load control may be demonstrated by a few examples.

The three-unit prosthesis

Figure 14-5 shows how radically the load to an individual implant may change depending on the number of implants and their positions. A three-unit prosthesis supported by two implants with a cantilever comprises three geometric load factors: (1) a number of implants that is less than the support value; (2) in-line placement; and (3) a cantilever. Especially if these factors are combined with elevated occlusal forces and/or excursive contacts, there is an increased probability of complications. Placement of a third implant would be good insurance in this situation. The staggering effect lends further opportunity to optimize the support but should

only be performed when anatomy so allows. Use of wider implants or components, again as anatomy allows, will still further reduce the impact of load on the mechanical parts of the structure.

Loss of one implant support

The loss of one of the supports will drastically change the situation. If one of three implants (see Fig 14-5) loses integration, the remaining implants will subsequently be subjected to increased load. A poorly tightened or misfitting unit in the prosthesis may, in the same manner, reduce the load capacity of that unit, transferring the load to the remaining support. A reduction from three to two implants will add one factor because of the loss of support; the in-line placement of the remaining two implants will add another; and, if the failing implant is a terminal one, the cantilever will also add a load factor. If this domino effect is not prevented with proper action, the complete restoration is at risk.

The three-unit prosthesis in the resorbed maxilla

Resorption in the maxilla may lead to a combined load factor, excessive height and offset (see Figs 14-8a and 14-9). If the support is based on two implants only, there will be two additional load factors (in-line and lack of support value). This situation of three factors demonstrates an essential risk of overload. The best situation would be the tripod support, but still the factor from excessive height and offset will remain. If the bone is weak, this will add another factor. Therefore, the combination of optimal implant support and optimal bone anchorage is essential for a predictable outcome in the resorbed posterior maxilla.

Single-molar replacement and occlusal control

A single-implant-supported molar restoration starts with two to three load factors (support value; in-line placement; and often a cantilever). If this is combined with soft bone in the maxilla, three to four load factors are at hand. Ensuring light centric occlusion in these situations might compensate for the geometric load factors and virtually eliminate the bending.²⁸ Therefore, occlusal control is a wise insurance policy for this modality, especially in weak bone. Other possibilities are to use two implants, which is ideal from a biomechanical point of view, or one wide implant, if anatomy allows, to increase mechanical strength and bone support.

Conclusion

There are inherent biomechanical differences in implant treatment of completely edentulous jaws and posterior partial situations. The latter situation does not benefit from cross-arch stabilization, and the difference in mobility between teeth and implants in the same quadrant means that the implants often will carry a major share of load. In the resorbed posterior maxilla, the possible load increase from overbridging the alveolar crest resorption and the nonoptimal primary implant stability are additional load factors to consider.

Primary implant stability is purely mechanical and is determined by the biomechanical properties of the bone and the surgical technique. Secondary stability depends on this primary anchorage plus the stability gained during the healing period as a result of bone formation and remodeling. If primary stability is high, a short, or even completely eliminated, mating period is probably sufficient without risking loss of stability. On the other hand, if the primary stability is poor, the treatment outcome will be dependent on the stability gained as a result of the healing.

Empirically, 6 months seems to be a sufficient healing period for most maxillary implants. However, from a biologic point of view, it is possible that the implants may gain in stability up to 18 months or even longer in accordance with the time needed for bone formation, remodeling, and maturation. Therefore, if bone quality is very poor, prolongation of the healing period may be one way to improve implant stability before loading.

When implants are placed simultaneously with a bone graft, the graft itself may not contribute to primary stability. The use of blocks of grafted bone as inlay is likely to improve primary stability, as is the addition of compacted bone chips to the implant bone site, while particulate bone grafts are less likely to support implants when added into the sinus. It is likely that the early function of the one-stage grafted implant is determined by the implant's stability in the residual basal bone rather than its stability in the grafted bone.

From a biologic point of view, a two-stage grafting procedure is preferable. In this way, the graft will be given time for revascularization and incorporation before the implants are introduced. At this time, the grafted bone will probably respond to the surgical trauma by initiation of the repair process around the implants, similar to that in normal bone.

By screening patients for load factors, it is possible to identify potential overload situations in advance of treatment and eliminate factors, when possible, or reduce their consequences by other actions. For the resorbed posterior maxilla, it is critical to evaluate the geometric load factors derived from the reduced height of the alveolar crest and the initially weak bone sup

port. Optimal number and position of implants and careful evaluation of required healing time are controlling parameters to overcome these difficulties. In addition, light and centric occlusal contacts may be used to reduce the consequences of potential load factors.

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Conclusion

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Subnasal Elevation and Bone Augmentation

Arun K. Garg, DMD

When the anterior maxillary residual crest is less than 10 mm in height, subnasal elevation, in conjunction with bone graft augmentation, can be used to provide adequate bone quantity and quality for implant placement. With subnasal elevation, the nasal mucosa can predictably be elevated 3 to 5 mm; this is followed by the placement of particulate bone graft material to augment the ridge. The periosteum of the labial aspect of the anterior maxilla is reflected to expose the inferior and/or lateral piriform rim. A nasal undercut region is typically present in the area of the lateral inferior piriform rim. In this region, the nasal mucosa may be elevated with a curette similar to that used to elevate the membrane during maxillary sinus-grafting procedures. Because the nasal mucosa is generally much thicker and more tear resistant, it is easier to elevate. However, because of the presence of an elastic fiber that causes the nasal mucosa to adhere more firmly to the underlying bone, greater pressure is required than is necessary for membrane elevation during maxillary sinus procedures.

Boyne¹ studied 10 cadaver specimens that had been edentulous in the maxilla for several years with various stages of resorption. He observed that implants placed in the alveolar crest after a sinus grafting procedure penetrated the nasal cavity with a high degree of frequency: in the canine to first premolar region, 90%; in the second premolar to first molar region, 80%. For this reason, when a routine sinus grafting procedure is performed, nasal membrane elevation may be indicated if there is a significant reduction in the transverse alveolar dimension, making the implants more likely to penetrate the nose.

In patients with unilateral or bilateral edentulism, antral-nasal inlay composite grafts can also be used. For edentulous patients with a compromised anterior maxillary region, complete-arch onlay grafts can be used to reduce the interarch space and create a more ideally sized and shaped arch. However, the presence of inadequate interarch space and a short upper lip may prevent the placement of a complete-arch onlay composite graft in totally edentulous patients.

A highly resorbed maxilla, which often presents with reverse architecture in the anterior maxilla where retained or supererupted mandibular incisor teeth have accelerated bone resorption into the basal bone, may leave only a few millimeters or complete dehiscence of the anterior nasal floor. In these situations, a 5- to 7mm block graft is placed after nasal mucosal elevation and inferior septoplasty are performed. When used in conjunction with alveolar augmentation grafting, this procedure provides additional stability and vertical dimension for the implants.

Despite these augmentation measures, inlay or onlay grafting procedures do not always adequately restore enough vertical bone for a fixed-removable prosthesis to be made. A prudent prosthetic choice then becomes the use of a continuous bar overdenture.²

Anatomic Considerations

Before performing surgery in this nasal region, the surgeon must have a working understanding of the anatomy of the nose. A recent study documented nasal mucosal maturation in 20 fetal heads between 8 and 24

weeks' gestation.³ The nasal cavity is initially lined with a single layer of flattened cells, which produces two to three layers of undifferentiated spherical cells. Olfactory epithelium lines the cranial portion of the human fetal cavity at 8 weeks' gestation. Pseudostratified ciliated cuboidal or columnar epithelium appears in the nasal cavity at 9 weeks' gestation and in the primitive ethmoidal sinuses and maxillary sinus infundibulum between 14 and 16 weeks' gestation. Goblet cells and glandular acini appear between 12 and 14 weeks' gestation. Initially, these goblet cells and glands are found predominantly in the anterior nasal cavity, but, at 24 weeks' gestation, they are more evenly distributed. Epithelial development of the nasal septum generally precedes that of the lateral nasal wall.

The arterial blood supply to the nose is derived from both the external and internal carotid arteries. The terminal branch of the maxillary artery (a branch of the external carotid artery) supplies the sphenopalatine artery, which supplies the lateral and medial walls of the nasal chamber. The anterior and posterior ethmoid arteries (branches of the ophthalmic artery, which is a branch of the internal carotid artery) supply the vestibule and the anterior portion of the septum. A few vessels from the greater palatine artery pass through the incisive canal of the palate to reach the anterior part of the nose.

Bone-Grafting Material

Autogenous bone is the bone-grafting material recommended for use in the nasal fossa. This material allows bone to form more rapidly and can be used where significant bone augmentation or repair is required. Autogenous bone can be harvested from the iliac crest, tibia, or intraoral sites, such as the mandibular symphysis, maxillary tuberosity, ramus, exostoses, and debris from an implant osteotomy.⁴⁻⁶ Intraorally obtained bone results in less patient morbidity than does bone from the iliac crest. In addition, the procedure can be easily accomplished in an office setting with the patient under parenteral sedation and local anesthesia.⁶ However, intraoral donor sites provide a smaller volume of bone than does the iliac crest.

The donor site that is chosen usually depends on the volume and type of bone desired. The grafted bone should be able to maintain its volume. Morselized and compressed cancellous bone or corticocancellous bone is preferred, but morticed blocks can also be fixated with miniscrews for either immediate or delayed implant placement. Alloplasts and allografts may be used to expand the autogenous graft. However, alloplasts or allografts are not recommended for subnasal grafting by themselves until more evidence of their effectiveness is established.

Subnasal Elevation and Augmentation Procedure

Surgical scrub is performed in the usual manner for the placement of implants. After the surgical team scrubs, the patient is draped. For intraoral preparation of the surgical site, a chlorhexidine antiseptic scrub and rinse can be used. Iodophor or chlorhexidine antiseptics can be used for preoperative extraoral scrubbing of the skin.

Infiltration anesthesia has been successfully used; however, a more significant regional anesthesia occurs when the secondary division of the maxillary nerve (V2) is blocked. With this technique, anesthesia of the hemimaxilla, side of the nose, cheek, lip, and sinus area can be achieved. Proper angulation of the needle prevents penetration into the nasal cavity through the medial wall of the pterygopalatal fossa. The use of a long-acting anesthetic (bupivacaine or etidocaine) is preferred. Block anesthesia produces a longer anesthetic effect in the maxilla than does infiltration anesthesia. Lidocaine 2 % with 1: 1 00,000 epinephrine is infiltrated into the labial mucosa and palatal region to decrease initial hemorrhaging and allow evaluation of the effectiveness of the local regional anesthesia.

A full-thickness incision is made on the crest of the maxillary ridge, from the distal end of the canine region to the distal end of the contralateral canine region (Fig 15-1). A vertical lateral releasing incision is then made at its distal extensions. The full-thickness tissue flap is reflected to expose the anterior maxilla to the nasal spine and the inferior and/or lateral piriform rim (Fig 15-2).

A nasal undercut region is typically formed at the junction of the lateral and inferior piriform rim that often corresponds to the area of placement for implants (canine area). The nasal mucosa in this region is elevated with a soft tissue curette (Figs 15-3 and 15-4), in a manner similar to that used for elevation of the mucoperiosteum in subantral augmentation procedures. Depending on the depth of the impression behind the piriform rim, the nasal mucosa is elevated approximately 3 to 5 mm and then augmented with graft material.

For subnasal augmentation, approximately 5 mL of cortical and trabecular autogenous bone is harvested from the mandibular symphysis and ground in a bone mill. This bone can then be mixed with freeze-dried bone allograft (if necessary to expand the volume) in a 50:50 ratio and compressed into a 1- to 3-mL tuberculin syringe. The mixture is applied from the most posterior regions of the nasal space to the most anterior labial region of the nasal spine and piriform rim (Figs 15-5 to 15-8).

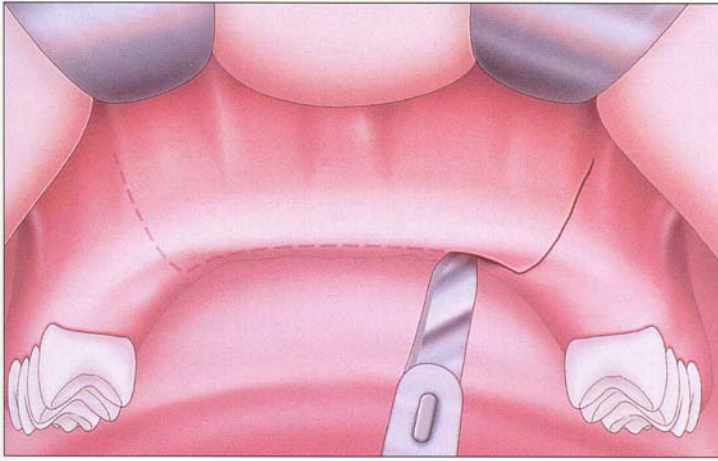
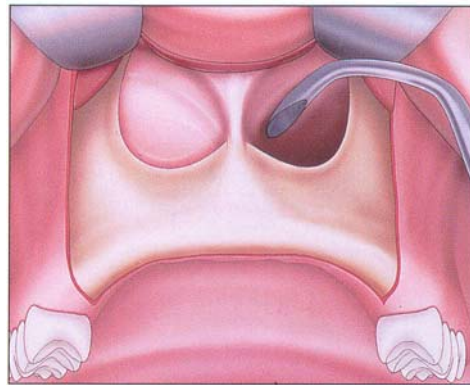
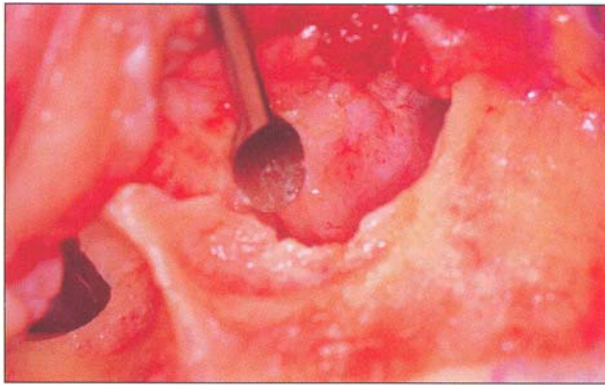


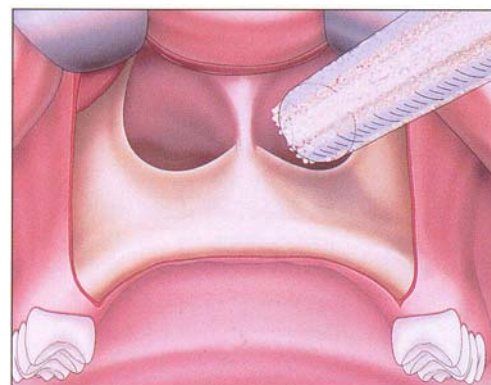
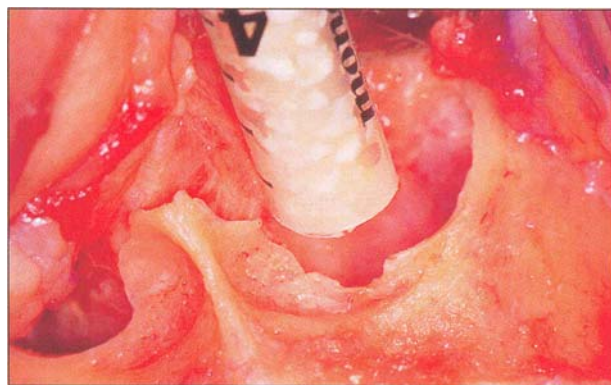
Fig 15-1 On the crest of the maxillary ridge, a full-thickness incision is made from the distal end of the canine region to the distal end of the contralateral canine region.



Fig 15-2 The facial bone is exposed to the nasal spine and the inferior and/or lateral piriform rim by reflecting the full-thickness tissue flap, followed by reflection of the maxillary labial periosteum.



Figs 15-3 and 15-4 A soft tissue curette is used to elevate the mucosa in the nasal undercut region approximately 3 to 5 mm.

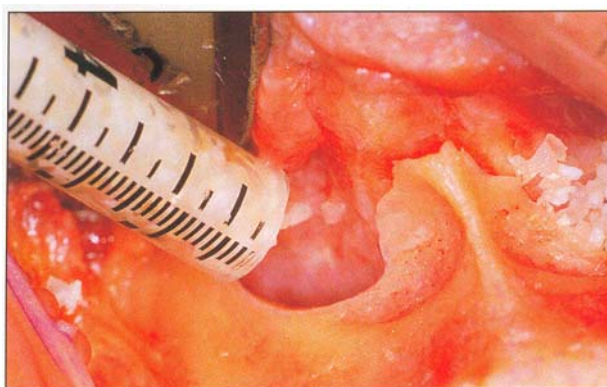


Figs 15-5 and 15-6 Approximately 5 mL of ground cortical and trabecular autogenous bone, harvested from the mandibular symphysis, is mixed with freeze-dried bone allograft in a 50:50 ratio and compressed into a 1- to 3-mL tuberculin syringe.

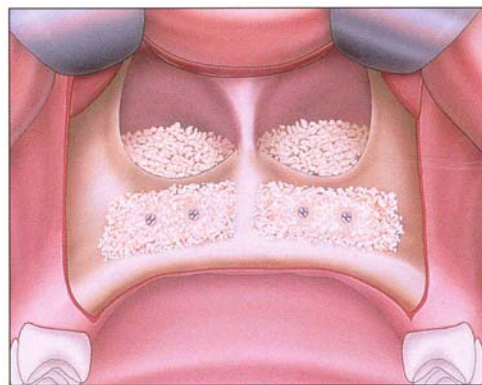
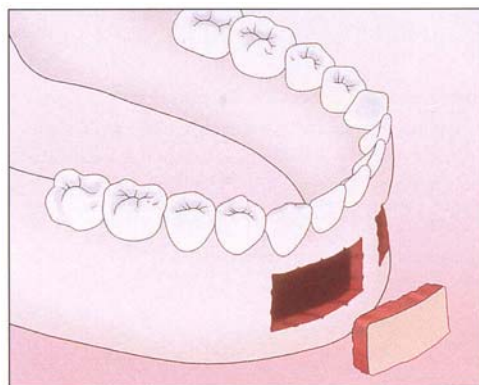
When subnasal augmentation is performed in conjunction with iliac graft reconstruction of the maxilla, a 2- to 5-mm septal reduction is performed in the anterior septum, taking care to avoid tears of the mucosal lining of the nasal septum. A block graft that is 5 to 7 mm in height is fixed with one or two miniscrews placed laterally; these can be left permanently if facial augmentation is performed over them. This provides enough stabilization for standard implants. If additional ridge width is necessary, block grafts from the anterior

mandible or ramus can be used (Figs 15-9 to 15-11) by fixation to the buccal aspect of the anterior maxilla. After maturation of the graft, the appropriate-sized implants can be placed (Fig 15-12).

Prior to suturing, the periosteum of the mucosal flap covering the graft is horizontally scored with a scalpel to allow tension-free wound closure. The primary crestal incision and the vertical relieving incisions are closed with 3-0 chromic or silk sutures in either an interrupted or continuous mattress fashion. This area



Figs 15-7 and 15-8 The ground bone-freeze-dried bone allograft mixture is applied from the most posterior regions of the nasal space to the most anterior labial region of the nasal spine and piriform rim.



Figs 15-9 and 15-10 Block grafts can be harvested from the anterior mandible or ramus, if additional ridge width is necessary.

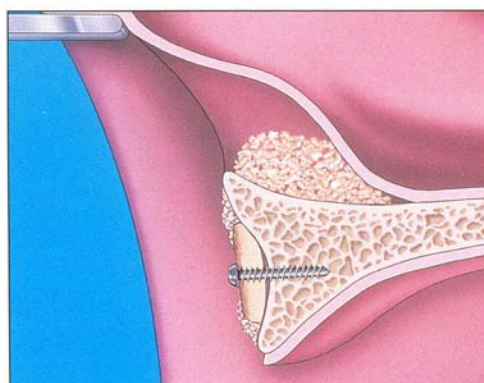


Fig 15-11 Miniscrews can be used to secure the graft in place.

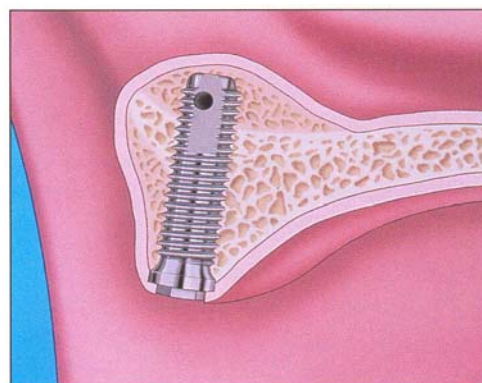


Fig 15-12 After the graft has matured, the appropriate-sized implants can be placed.

should be permitted to heal for 4 to 6 months before implant placement. In addition, the provisional partial denture or complete denture should be adjusted to avoid contact with the grafted area.

Postoperative Instructions

The postoperative instructions are similar to those for most oral surgery and sinus-manipulation procedures. The patient should use a chlorhexidine mouthrinse twice a day for 2 weeks to reduce the chances of infection. The patient should avoid blowing the nose, creating negative pressure while sucking liquid through a straw, and smoking cigarettes for at least 1 week following surgery. (Smoking can also compromise healing of both the intraoral and subnasal graft regions.) The patient should cough with an open mouth to relieve pressure.

Potential Complications

Although bleeding is rarely a concern during the subnasal elevation and bone augmentation procedures, if it does occur, bone wax or electrocautery can be used to contain the vessels. Postoperative swelling in the region is common, but the pain is less severe than that following the placement of mandibular implants or a sinus grafting procedure.

Inadequate soft tissue management has the most devastating effect during the immediately postoperative phase. Blood supply to the graft can be compromised by improper flap design. In addition, excessive tension on the incision line can cause the line to open and expose the graft. As a result, there can be delayed healing, leakage of graft material into the oral cavity, and increased risk of infection.

During placement, an implant may penetrate the nasal fossa or even the maxillary sinus because of insufficient grafting of the area. If this occurs, the implant can become accidentally displaced into the sinus or nose during the healing period. Tight fixation of the implants should always be confirmed at the time of surgery, and any implant that is mobile or inadequately stabilized should be removed.⁷

When the implant is not placed sufficiently in bone, especially when soft tissue may adhere to the implant, downgrowth of the epithelium may compromise osseointegration. However, one study reported that, during healing, no undesirable side effects occurred secondary to incidental penetration of titanium screws into the maxillary sinus or nasal cavity, as long as the implant was located sufficiently in bone.^s

If an implant or graft becomes infected, local spread of inflammation from an infected maxillary implant

can cause rhinitis and sinusitis. Maxillary sinusitis can also occur when an implant becomes displaced and acts as a foreign body, causing chronic infection.⁷

If septoplasty procedures are performed, care must be taken to avoid septal displacement or deviation. This generally does not occur if only the anterior inferior septal area is resected.⁹

Conclusion

For patients who present with significant bone loss in the anterior maxillary ridge, ridge-augmentation procedures may be required to increase the height and/or width for implant placement. When additional height is needed, subnasal elevation can be used in combination with bone graft augmentation. Because the nasal mucosa is generally much thicker and more tear resistant than other membranes (such as the mucoperiosteum), it is easier to elevate. With this technique, the nasal mucosa can predictably be elevated 3 to 5 mm, followed by placement of particulate bone graft, or up to 10 mm if septoplasty and block grafting are performed. This approach provides the surgeon with an easier means of augmenting the vertically deficient anterior maxilla in preparation for subsequent implant placement.

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Bone Graft Physiology with Use of Platelet-Rich Plasma and Hyperbaric Oxygen

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What clinicians loosely refer to as a "bone graft" for reconstruction of the atrophic maxilla really amounts to a marrow transplant. It is aimed at obtaining osteocompetent cells, which are essentially the endosteal osteoblasts from the surface of cancellous bone trabeculae and the cancellous marrow stem-cell population, from bone donor sites such as the ilium and tibial plateau.¹⁻⁴ The graft itself contains these osteocompetent cells and islands of mineralized cancellous bone, fibrin from blood clotting, and platelets within the clot. The endosteal osteoblasts and marrow stem cells survive the first 3 to 5 days largely because of their surface position and their ability to absorb nutrients from the recipient tissues via simple diffusion. The osteocytes within the mineralized cancellous bone die because their encasement in mineral serves as a nutritional barrier.

Initial Regenerative Process

Within the graft, the platelets entrapped in the clot degranulate within hours of graft placement, releasing platelet-derived growth factor (PDGF) and transforming growth factors beta 1 (TGF- β_1) and beta 2 (TGF- β_2). Both of these factors begin the bone regenerative process (Fig 16-1). Platelet-derived growth factor binds to endothelial cells to initiate the ingrowth of capillaries, while TGF- β_1 and TGF- β_2 bind to the endosteal osteoblasts and marrow mesenchymal stem cells to initiate mitoses to increase their numbers as well as

stimulate their production of osteoid. This continues during the first 3 days of the graft, at which time capillaries are already seen to be entering the graft (Fig 16-2). However, by this time, the platelets have degranulated and are no longer a primary source of growth factors to drive the bone regenerative process. At this time, macrophages take over this role.

Macrophages were initially attracted to the graft as circulating monocytes of free tissue cells by the inherent oxygen gradient in the graft. The hypoxia in the graft of 0 to 5 mm Hg oxygen tension, compared to the normoxia of the adjacent tissue, which is 45 to 55 mm Hg oxygen tension, creates an oxygen differential greater than the 20 mm Hg oxygen tension to which the macrophage is programmed to respond. Thus, macrophages, which are very prolific and efficient synthesizers of growth factor, drive the remaining bone regeneration of the graft and healing. Essentially, macrophages secrete the same PDGF and TGF- β proteins, but also secrete basic fibroblast growth factor and vascular endothelial growth factors, among others. Thus, the inherent properties of the wound (particularly the oxygen gradient, PDGF, and TGF- β) initiate early angiogenesis from surrounding capillaries and mitogenesis of the transferred osteocompetent cells.

Complete revascularization of the graft is seen by day 14 (Fig 16-3). By this time, the endosteal osteoblasts have already laid down osteoid on the original bone trabeculae and the marrow stem cells have dramatically increased in number and have begun differentiating into osteoblasts. As capillaries revascular

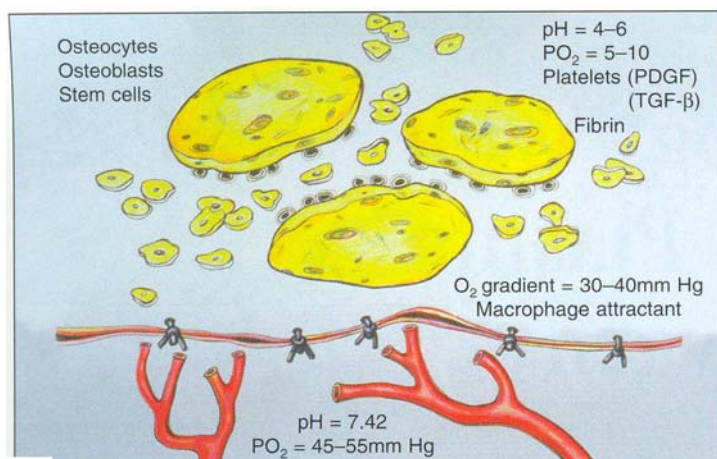


Fig 16-1 Platelets entrapped in the blood clot degranulate releasing platelet-derived growth factor (PDGF) and transforming growth factors beta (TGF- β) 1 and 2. These factors begin the bone regenerative process.

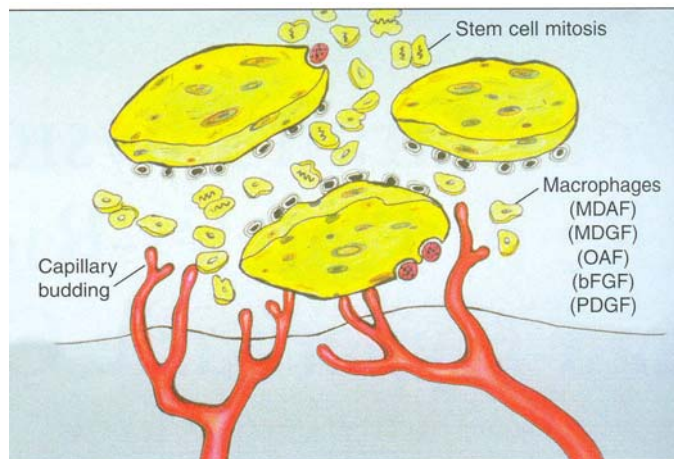


Fig 16-2 During the first 3 days of graft placement, capillaries begin entering the graft. (MDAF) macrophage-derived angiogenic factor; (MDGF) macrophage-derived growth factor; (OAF) osteoclast activating factor; (bFGF) basic fibroblast growth factor; (PDGF) platelet-derived growth factor.

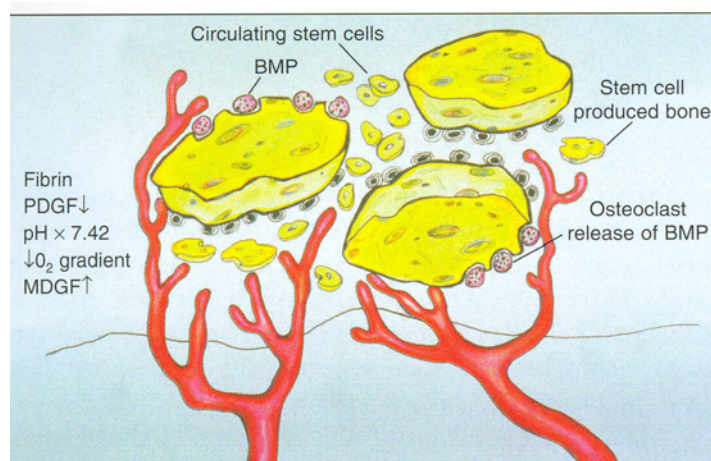


Fig 16-3 Complete revascularization of the graft is seen by day 14. (BMP) Bone morphogenetic protein; (PDGF) platelet-derived growth factor; (MDGF) macrophage-derived growth factor.

ize the graft, they effectively reduce the oxygen gradient, thus creating a shut-off mechanism to the macrophage, which prevents excessive angiogenesis.

During the first 3 to 7 days, the stem-cell population and endosteal osteoblasts produce only a small amount of osteoid. However, once the vascular network is established, osteoid production accelerates, presumably as a result of oxygen and nutrient availability. The initial formation of osteoid develops on the surface of the mineralized cancellous trabeculae from the endosteal osteoblasts. Shortly thereafter, individual osteoid islands develop between the cancellous bone trabeculae, presumably from the stem cells transferred to the graft. A third source of osteoid production develops from circulating stem cells, which are also attracted to the biochemical environment of the wound.² It is believed that these stem cells seed into the graft, where they proliferate and contribute to the osteoid production.

Phase 1 Bone Regeneration

During the first 3 to 4 weeks, this biochemical and cellular phase of bone regeneration proceeds to clinically consolidate the graft by coalescing individual osteoid islands, surface osteoid on cancellous trabeculae, and host bone. This process is essentially transplanted *osteogenesis* (Fig 16-4). However, it uses the fibrin network of the graft as a framework. This is referred to as *osteoconduction*, which provides a scaffold for what has been called "creeping substitution" but in this sense is "creeping formation." That is, the normally nonmotile osteoblasts can be somewhat motile via the process of endocytosis along a scaffoldlike fibrin. The process of endocytosis is merely the transfer of cell membrane from the retreating edge of the cell, through the cytoplasm as a vesicle, to the advancing edge to reform a cell membrane and thus increase the cellular surface area at the advancing edge⁶ (Fig 16-5).

This mechanism slowly advances the cell and allows it to secrete its product in the process. In this case, the product is osteoid on the fibrin network. This cellular regeneration is often referred to as *phase 1 bone regeneration*,¹ or the *woven bone phase*. By the time it is nearly complete (4 to 6 weeks), sufficient osteoid production and mineralization have occurred to permit graft function. At this stage, the bone has formed without going through a chondroblastic phase and histologically appears as random cellular bone that a pathologist would refer to as *woven bone*? (Fig 16-6).

Because the amount of bone formed during phase 1 will depend on osteocompetent cell density, donor sites with the highest cancellous trabecular bone are chosen. In rank order, the posterior and anterior ilia, tibial plateau, and mandibular symphysis have been found to be potential donor sites with greater cancellous bone

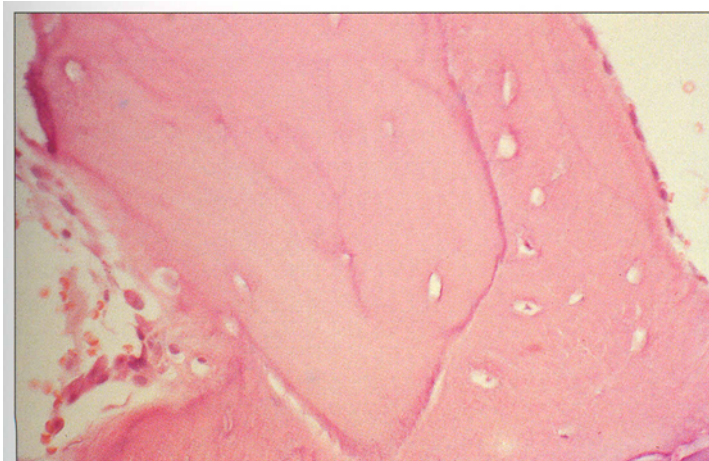


Fig 16-4 Surface osteoid production is related to transplanted osteogenesis.

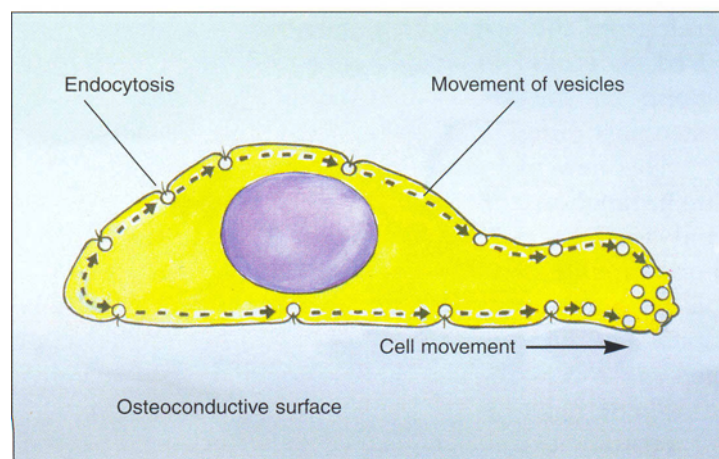


Fig 16-5 Endocytosis is the process by which osteocytes can produce bone on the surface of fibrin in a bone graft or a roughened surface of a dental implant.

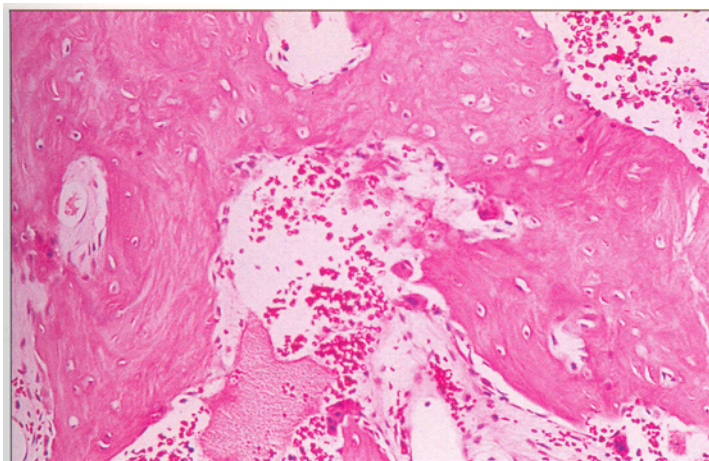


Fig 16-6 Woven bone from a phase 1 undergoing osteoclast resorption. Phase 1 bone is to be replaced by phase 2 bone.

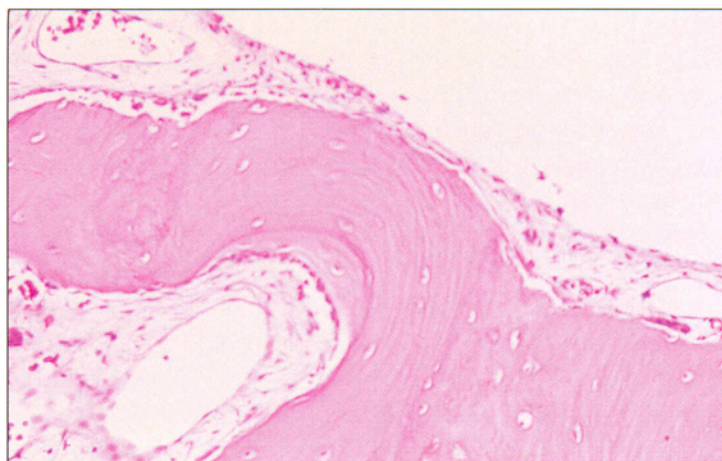


Fig 16-7 Lamellar phase 2 bone is replacing woven phase 1 bone.

than the calvarium, rib, or fibula. In addition, enhanced phase 1 bone yields are achieved by compacting the graft material. Technically, this is often accomplished with a bone mill, followed by syringe compaction, and then by further compaction into the graft site with bone-packing instruments.

Phase 2 Bone Regeneration

The cellular bone regeneration that has occurred in phase 1 produces this disorganized woven bone that is structurally sound but not to the degree of mature bone. The random organization and hypercellular nature of this bone is similar to that seen in a fracture callus. This bone will undergo an obligatory resorption and replacement type of remodeling. Eventually, it is replaced by phase 2 bone, which is less cellular, more

mineralized, and structurally more organized into lamellar bone.^{1,2}

The replacement of phase 1 bone by phase 2 bone (woven bone by lamellar bone), like all bone remodeling, is initiated by osteoclasts (Figs 16-6 and 16-7). Osteoclasts are fused mononuclear cells that arrive at the graft site through the newly developed vascular network. It is theorized that these osteoclasts resorb phase 1 bone in a normal remodeling-replacement cycle.

As both the phase 1 bone and the nonviable original cancellous bone trabeculae are resorbed, bone morphogenetic protein (BMP) and insulin-like growth factors 1 (IGF1) and 2 (IGF2) are released. As with normal bone turnover, BMP, IGF1, and IGF2 act as the link, or couple, between bone resorption and new bone apposition. Such growth and differentiation factors are deposited into the mineral matrix of bone by osteoblasts during osteoid production. Stem cells in the

graft from the original transplantation and newly arrived stem cells from local tissues and the circulation respond to the released BMP, IGFb and IGF2 by osteoblast differentiation and new bone formation.

This new phase 2 bone forms as the jaw and graft are in function. It responds to the demands placed on it and develops mature haversian systems and lamellar bone capable of withstanding the normal shear forces placed on the jaw through opening and closing functions. The bone is capable of tolerating impact compressive forces typical of denture and implant-borne prosthetic functions.

Histologically, such grafts enter a long-term remodeling consistent with normal skeletal turnover. A periosteum and endosteum develop as part of this long-term remodeling cycle. The graft cortex never becomes as thick as a normal jaw cortex, and the graft itself retains a dense, cancellous trabecular pattern. This pattern is advantageous in promoting osseointegration and is adaptable to a variety of functional stresses. Over several years, the graft takes on the radiographic morphology and cortical outlines of a mandible or maxilla.

The surgeon can use this knowledge of bone physiology to plan preprosthetic rehabilitation. Essentially, the graft can begin full function at 6 weeks. Subsequent preprosthetic procedures, such as skin graft vestibuloplasties, can be accomplished at 4 months, which is the time when a functional periosteum has formed. Similarly, and often together with vestibuloplasties, osseointegrated dental implants may be placed. Such implants osseointegrate into bone grafts rapidly and may be activated as soon as 4 months.

Platelet-Rich Plasma: Growth Factor Enhancement for Bone Grafts

Today the emerging technology of growth factors offers earlier bone regeneration and regeneration of more mature and denser bone. This is particularly attractive for grafting the edentulous and severely atrophic maxilla, which is most often found in elderly patients, patients with osteoporosis, and in those with previous dental disease and subsequently scarred and altered tissues. All of these factors reduce the success rate of both bone grafts and of osseointegration.

The biochemistry of the recipient tissue and the graft itself is, as previously stated, largely inherent. However, at this time, studies and experience with platelet-rich plasma (PRP) additions to the graft have shown early consolidation and graft mineralization in one half the time and a 15% to 30% improvement in trabecular bone density.¹⁰ The concept is that PRP, which is a fibrin clot (sometimes referred to as *fibrin glue*), is rich in platelets, which in turn release PDGF and TGF- β .

Platelet-derived growth factor appears to be the first growth factor present in a wound and initiates connective tissue healing, including bone regeneration and repair. The most important specific activities of PDGF include mitogenesis (increase in the cell populations of healing cells), angiogenesis (endothelial mitoses into functioning capillaries), and macrophage activities (debridement of the wound site and a second-phase source of growth factors for continued repair and bone regeneration).^{11,12} There are approximately 0.06 ng of PDGF per 1 million platelets, or about 1,200 molecules of PDGF per individual platelet, underscoring this molecule's great potency.^{13,14} It is theorized that this enhanced quantity of PDGF initiates the osteocompetent cellular activity more completely than what will inherently occur in the graft and clot milieu alone.^{11,12} In addition, the enhanced fibrin network created by PRP is believed to enhance osteoconduction throughout the graft-supporting consolidation.

Transforming growth factor beta is a term applied to a super family of growth and differentiating factors, of which the 13 described BMPs are members.¹⁵ The TGF- β_1 and TGF- β_2 proteins are the more protean and generic growth factors, involved with general connective tissue repair and bone regeneration.^{16,17} These TGF- β proteins represent a mechanism to sustain a long-term healing and bone regeneration module and even evolve into a bone-remodeling factor over time. The most important functions of TGF- β_1 and TGF- β_2 appear to be the chemotaxis and mitogenesis of osteoblast precursors and the ability to stimulate their deposition of the collagen matrix of wound healing and of bone.¹⁸ In addition, the two TGF- β proteins inhibit osteoclast formation and bone resorption, thereby favoring bone formation over resorption by two different mechanisms.¹⁹

From previous work and new knowledge of growth factor influences, a reasonable model for the bone regeneration observed in cancellous cellular marrow grafts has been developed¹⁰ (see Figs 16-3 to 16-5). This model also points out where at least these two fundamental growth factors influence bone regeneration normally and how increased quantities of each through PRP produces a faster rate of bone formation and a greater quantity of bone. The amplification of the influence of PDGF and TGF- β through the technique of platelet sequestration and concentration into a PRP is seen as an available and practical tool to enhance the rate of bone formation and the quantity of bone formed (Figs 16-8 and 16-9).

The fact that PRP is an autologous preparation eliminates concerns of disease transmission or immunogenic reactions that exist with allogeneic or xenogeneic preparations. Because PRP is prepared at the time of surgery, the possibility of mislabeling a sample (as might occur when a laboratory system is used) is also



Fig 16-8 Platelet-rich plasma collection provides a concentrated source of platelets.

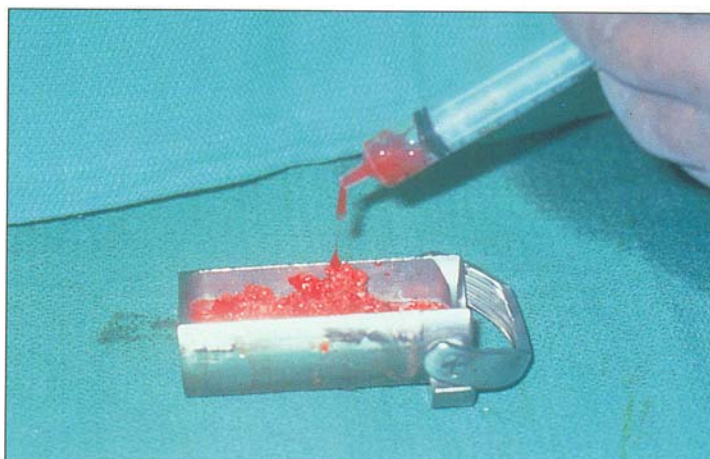


Fig 16-9 Platelet-rich plasma is added to particulate bone graft to gain stimulation by growth factors contained within the platelets.

eliminated. Its use in grafts of the severely atrophic maxilla seems to increase the overall success rate of osseointegration, as well as develop a more dense bone sooner.¹⁰

This relatively crude mechanism of adding biochemical wound enhancers may be a harbinger of the future. Clinicians and researchers are currently looking forward to the clinical availability of recombinant DNA-produced human BMP (rhBMP). Animal studies and early multicenter human trials indicate that rhBMP (in an appropriate resorbable carrier) has the capability of producing physiologically normal bone, which may eliminate the need for bone grafting in the near future.

Special Considerations in Irradiated Patients

Osseointegration of dental implants is feasible in the oral cancer patient who has undergone radiotherapy. This is made possible mainly by the use of hyperbaric oxygen in such patients and a slight modification in the surgical and prosthetic aspects of patient care.

Fundamentally, radiation-damaged bone and soft tissue have been shown to be hypovascular, hypocellular, and hypoxic ("the 3-H principle").²⁰ Therefore, when challenged with healing, such as that required when a dental implant is placed, the tissue often cannot meet the metabolic and oxygen demands of healing. The effect of hyperbaric oxygen on irradiated tissue is to increase the capillary density (angiogenesis) from a baseline of 30% of nonirradiated tissue to as much as 75% of nonirradiated tissue (Fig 16-10). Although this does not normalize irradiated tissue, it brings it into the

range of uncomplicated wound healing, including bone remodeling and osseointegration.

Our current experience with osseointegrated implants placed in irradiated bone has been 3- to 5-year implant survival rates of 84%, with an incidence of osteoradionecrosis of 1 %. Studies have shown that implants placed in irradiated bone take longer to osseointegrate and do not osseointegrate to the same degree as normal bone (39% bone-to-metal contact versus 47% bone-to-metal contact, respectively).[?] Nevertheless, implants placed in irradiated bone supported by hyperbaric oxygen have been clinically supportive of prostheses.

The recommended protocol for hyperbaric oxygen therapy before dental implants are placed in irradiated bone is 20 sessions of 100% oxygen at 2.4 ata (absolute atmospheres of pressure) for 90 minutes each session. These 20 treatment sessions accomplished prior to dental implant placement are followed by 10 additional sessions after implant placement with the same treatment parameters. Because the angiogenic effects of hyperbaric oxygen are permanent, dental implant placement or tooth removal that may be required years later would not require additional hyperbaric oxygen therapy (see Fig 16-10).

Because hyperbaric oxygen improves irradiated tissues to only 75% than that of nonirradiated tissues, some surgical precautions must be exercised to preserve the blood flow to the native bone. These surgical precautions include a minimal reflection of lingual periosteum in the mandible and palatal periosteum in the maxilla, which are their major vascular pedicles. In particular, preservation of the lingual periosteum is required. It is also prudent to use the widest and longest implants which, therefore, have the greatest surface

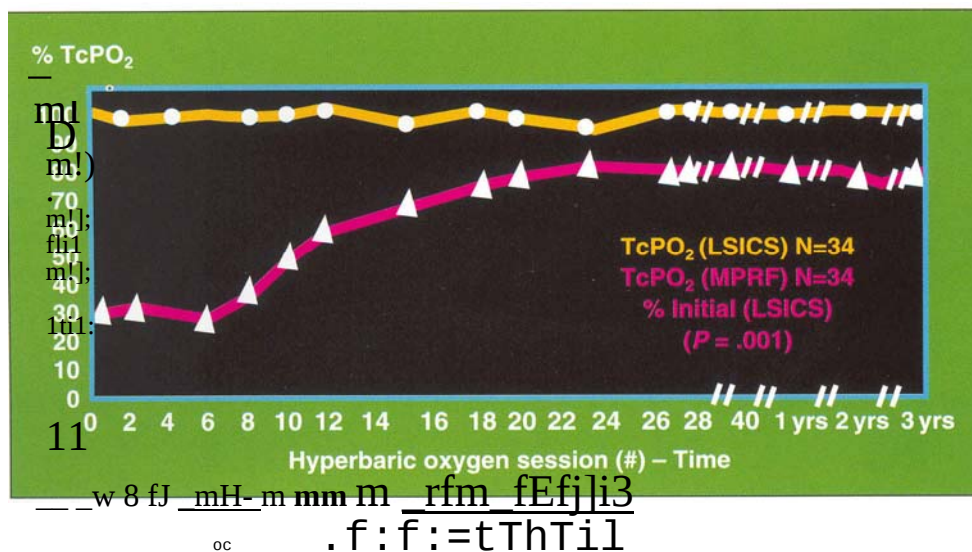


Fig 16-10 Vascular density of irradiated tissue as a function of hyperbaric oxygen exposures.

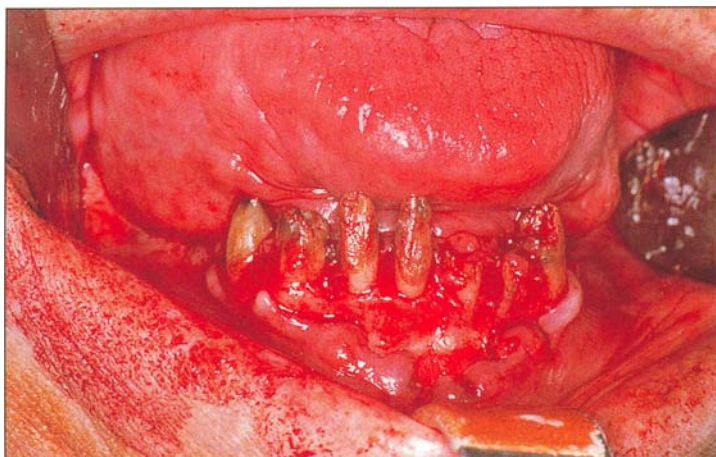


Fig 16-11 Teeth are removed from an irradiated mandible after the hyperbaric oxygen protocol.

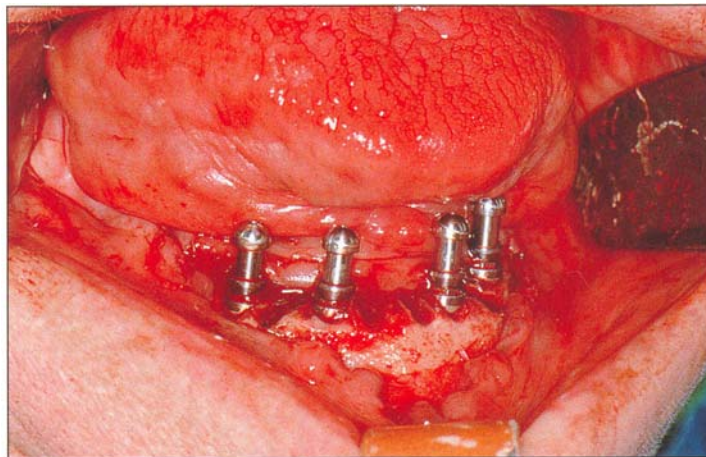


Fig 16-12 Implants are placed immediately in irradiated bone.

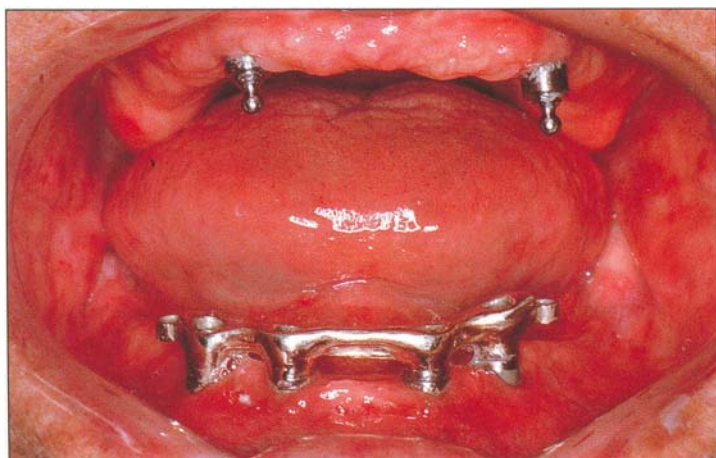


Fig 16-13 The mandible is restored with a Hader bar and clip denture. The implant success rate in irradiated bone is 84%. Maxilla has two implants restored with a-rings and a denture.



Fig 16-14 The appliance is functional at the 4-year follow-up.

area that the bone morphology will permit. This will compensate for the slightly reduced percentage of bone-to-metal contact developed in irradiated bone. It is also prudent to place additional implants to distribute occlusal loads and to compensate for any implants that fail to osseointegrate.

Because the rate of bone remodeling is lessened in irradiated bone, it is recommended that a full 6-month osseointegration period be allowed before the implants are uncovered and the fabrication of a prosthesis is begun. For larger edentulous spans, implant-retained prostheses or fixed-removable prostheses (hybrid prostheses) are preferred over totally fixed prostheses, which place greater stress on the underlying bone.

With the use of hyperbaric oxygen and these surgical and prosthetic modifications, the irradiated patient can be afforded the same benefits of dental implants as the nonirradiated patient (Figs 16-11 and 16-12). As stated earlier, our experience with more than 1,000 implants placed in irradiated bone has been a 3-year functional survival rate of 84 % and a very low incidence of osteoradionecrosis (Fig 16-13). Certainly the benefits of hyperbaric oxygen and the inherent biomechanical tolerance of osseointegrated implants are responsible for this response rate (Fig 16-14).

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Combined Sinus Grafting and Le Fort I Procedures

Ole T. Jensen, DDS, MS

Treatment of the completely edentulous and resorbed maxilla affords an opportunity to adjust maxillary position in relation to the mandible by using a modified Le Fort I osteotomy technique.¹ When the deficiency of the maxilla is such that iliac bone grafting is justified, the bone harvested can be used to support the osteotomy procedure as well as for sinus and alveolar augmentation.

The determination of the need for a Le Fort I osteotomy is based on cephalometric analysis and articulator-mounted casts. In addition, the final treatment plan must address whether restoration will involve fixed or removable prostheses. Because the highly resorbed maxilla can rarely be reconstructed to support a fixed restoration, a coordinated effort between prosthetic and surgical disciplines is needed to ensure that a reasonable and achievable reconstructive goal can be obtained.² Vertical alveolar augmentations greater than 10 mm may lead to early wound dehiscence and may be unstable long term, being prone to resorption (see Chapter 9). It is better to attempt an achievable goal in the range of 5 to 10 mm and gear efforts toward the amount of bone needed to place a sufficient number of implants of adequate length.

Combination of Sinus Augmentation and Le Fort I Osteotomy

Ten years of experience with vertical alveolar augmentations combined with sinus augmentations has demonstrated not only the vertical stability of the alveolar

graft (Figs 17-1a and 17-1b) but that the sinus graft is even more stable³ (Figs 17-1c and 17-1d). In many cases, sinus augmentations of 15 mm or more have been stable for several years (see Chapter 19)⁴ (Figs 17-1c to 17-1g). Given this favorable experience, the next logical step is to advance the maxilla into an orthognathic position, by using the well-established Le Fort I procedure combined with the now equally wellfounded sinus grafting procedure. When these procedures are performed together, it often minimizes or eliminates the need for vertical alveolar augmentation.

The Le Fort I osteotomy cuts are made carefully to preserve the sinus membrane. After sinus membrane elevation (of the entire sinus bilaterally) is accomplished, the maxilla is mobilized forward and downward and fixed in an orthognathic position. This highly technical procedure requires a modification of the Le Fort I procedure sequencing:

1. The osteotomy is conducted in such a way as to preserve and elevate both the sinus and nasal membranes (Fig 17-2a).
2. Rigid fixation with resorbable bone plates and screws is applied to establish the desired position of the resorbed maxillary residuum⁵ (Figs 17-2b to 17-2d).
3. Following fixation of the maxilla, which may include widening of the maxilla, the sinus floor is grafted and the lateral alveolar maxilla is augmented with struts of corticocancellous or cancellous marrow bone over the resorbable fixation system (Fig 17-2e). (This "outside" grafting can be fixed with titanium screws, which, unlike the "inside" grafting fixation, will be accessible for removal at a later stage.)

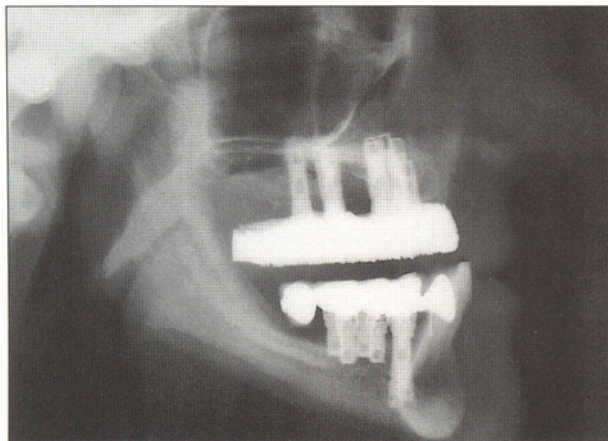


Fig 17-1a

Figs 17-1 a and 17 -1 b Radiographs of patient 9 years after iliac grafting by combined vertical augmentation and sinus grafting. (Courtesy of Dr Ronald Yaros.)

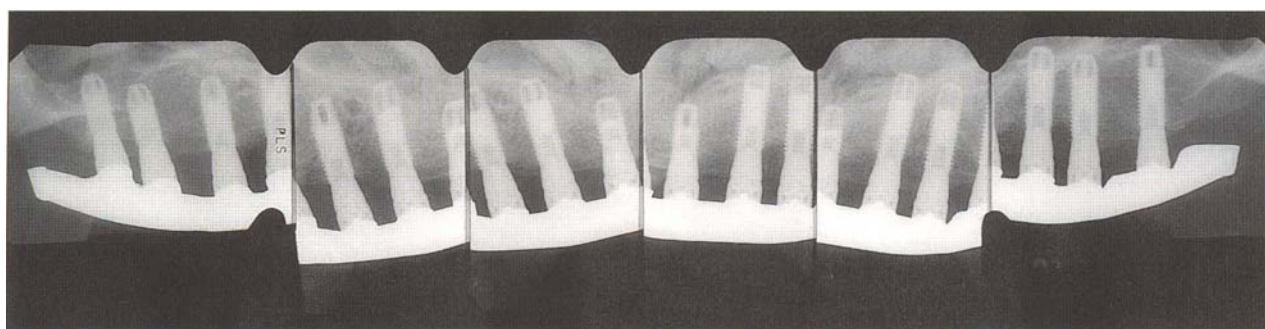
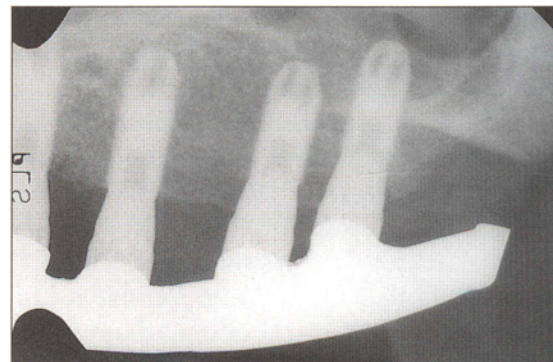
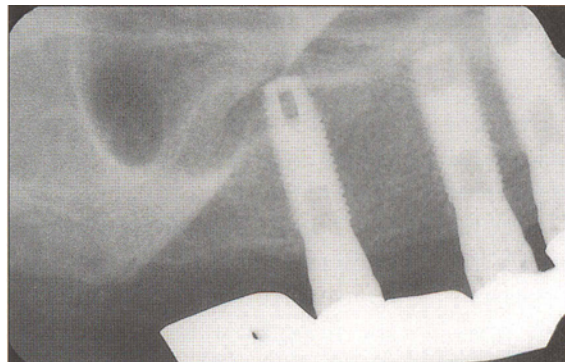


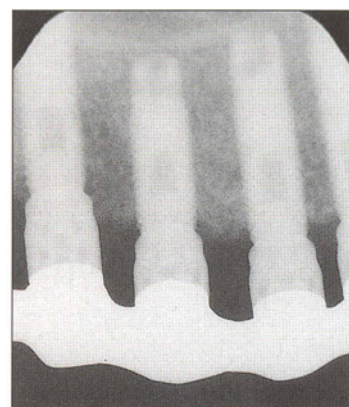
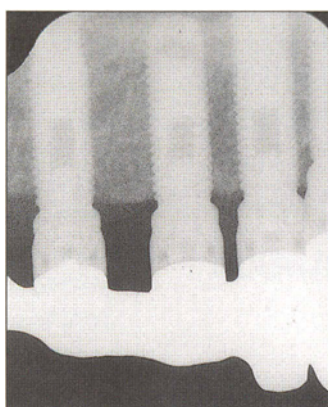
Fig 17-1b



Fig 17-1c Note the stability of alveolar augmentation anteriorly, where there had been initially only a sliver of alveolar bone.



Figs 17-1 d and 17 -1 e There has been no discernible loss of bone graft height within the sinus.



Figs 17 -1f and 17 -1 g Sinus and alveolar bone levels are stable in another patient 7 years after combined iliac grafting.

Fig 17 -2a The nasal and sinus cavities are still veiled by the elevated nasal and sinus mucosa with the maxilla in a downfractured Le Fort I position. (Courtesy of Dr Louisa Gallegos.)



Figs 17-2b to 17-2d Following maxillary advancement and sinus and nasal grafting, resorbable bone plates are used to fix the position of the maxilla forward about 5 mm and downward about 10 mm.



Fig 17-2b

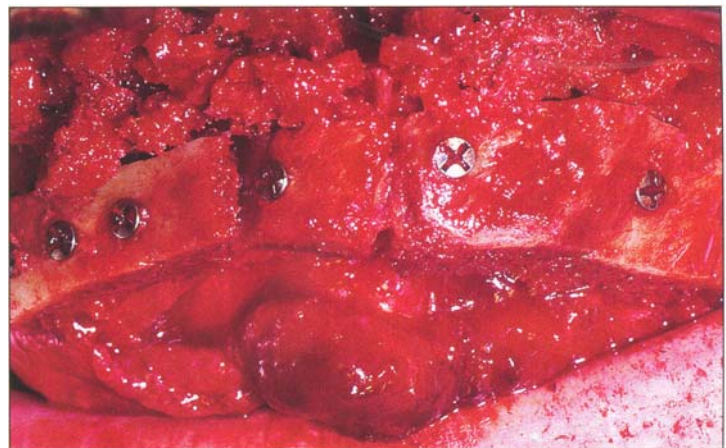


Fig 17-2c



Fig 17-2d

Fig 17 -2e The maxilla is then reconstructed by about 5 mm of lateral augmentation and some vertical anterior augmentation of the alveolus.



4. A block of bone is interposed in the gap between the pterygoid plate and posterior maxilla that has been created by the maxillary advancement, as is done in traditional maxillary downgrafts.⁶
5. Because the maxilla is usually brought inferiorly several millimeters, care is taken to interpose the graft in the nasal fossa, usually in a combination of particulate and block form supported by resorbable fixation. Anterior alveolar augmentation overlays this and can be aided by retaining the anterior nasal spine (see Fig 17-2b).
6. Barrier membranes are advocated if it is important to limit resorption of the graft laterally.⁷
7. Placement of implants should be delayed until graft incorporation 6 months later, when ideal placement locations can be obtained. (Immediate placement requires engaging at least a portion of the host bone and is generally reserved for less resorbed ridges.)⁸
8. Three-layer wound closure is performed with resorbable suture in all three layers.

Classification of Resorbed Maxillae

Many variables, both physiologic and mechanical, make it impossible to take the same approach in every case. Because of this, guidelines are suggested by way of a classification of resorbed maxillae and their corresponding treatment solution. Previous classifications have been based on the residual bone available for implants or on a descriptive gradation of bone resorption.⁹⁻¹¹ This classification of bone resorption is based on the suggested treatment options required to "normalize" or "functionalize" the maxilla through grafting and orthognathic surgery. Four classes of edentulous maxillae are suggested by this method.

Class I: Orthognathic maxilla

- . Requires minor grafting laterally
- . No vertical grafting required
 - Sinus grafting (usually minor) may or may not be needed
- . At least eight implants can be placed
- . *Treatment protocol:* Minor grafting in conjunction with implant placement

Class II: Retrodisplaced maxilla; otherwise Class I (Figs 17-3a to 17-3h)

- *Treatment protocol:* Le Fort I advancement; sinus grafting; limited simultaneous or delayed implant placement (Figs 17-4a and 17-4b)

Class III: Retrodisplaced maxilla; severe lateral bone loss, vertical bone maintained (knife-edged ridge)

(see Figs 17-2a to 17-2e)

- . *Treatment protocol:* Le Fort I advancement; sinus grafting; nasal grafting; down grafting; lateral grafting; limited or delayed implant placement preferred (Figs 17-5a to 17-5d)

Class IV: Retrodisplaced maxilla; horizontal and vertical bone loss (Figs 17-6a to 17-6d)

- . *Treatment protocol:* Le Fort I advancement; sinus grafting; nasal grafting; down grafting; lateral grafting; delayed implant placement

Class IV, subclass a: Total anterior vertical bone loss (primarily)

Class IV, subclass b: Total anterior and posterior vertical bone loss

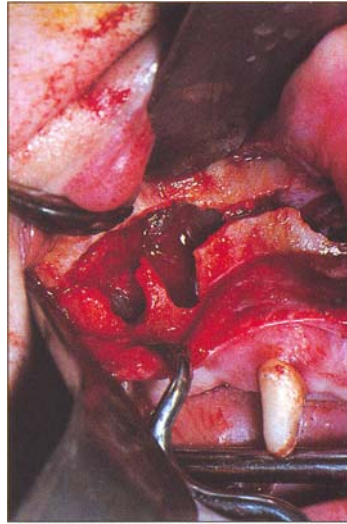
Goals for Ideal Restorative Result

The overall goals are to establish an osseous morphology, using the available maxilla as a strut of bone to fixate to and from which to supply vascular capacity and inductivity, and to establish a biologic receptacle for osseointegration. Implant dental restoration is then accomplished in both an orthognathic and minimally cantilevered occlusal scheme.¹²⁻¹⁴ To approach an ideal restorative result, despite variability in bone graft incorporation and uneven bone graft resorption or even relapse of the advancement osteotomy, the use of relatively small corrections in each of these three planes of space is advocated. If the advancement of the maxilla is not too great, less relapse is expected. If the augmentation is not too extensive or far removed from the basal bone (Fig 17-7), less dimensional change is expected from late remodeling and implant loading.¹⁶ Furthermore, less sinus bone grafting is needed, and the graft is placed where the sinus membrane is preserved, so that a closed wound environment can be maintained, providing a solid and predictable framework for a stable expansion of the osseous bed. By using these three planes of space in the treatment of the highly resorbed maxilla, the final stability is improved despite the added complexity of this approach.

Figures 17-8a to 17-8m show a Class III case where a Le Fort I osteotomy, sinus grafting, and lateral grafting



Fig 17 -3a This 41-year-old woman had lost all the maxillary teeth except for the canines and first molars, which, although severely periodontally compromised, were used to support a provisional fixed partial denture. The prosthetic teeth were about 1.5 times the normal length because of bone loss. Here the maxilla is about ready to be downfractured and advanced following sinus elevations. (Courtesy of Dr Gary Hoffman and Dr Pamela McClain.)



Figs 17 -3b and 17 -3c The sinus cavity is filled with iliac graft.

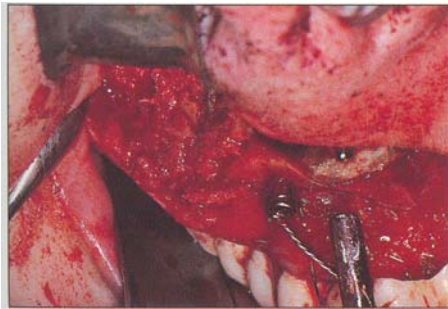


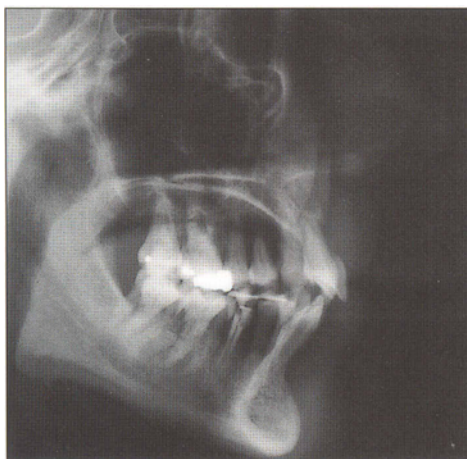
Fig 17 -3d The maxilla is fixated down and forward.



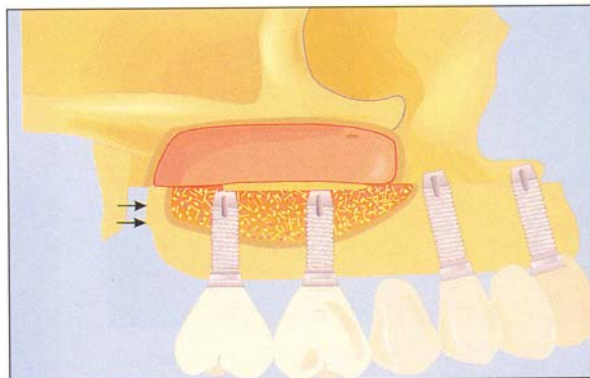
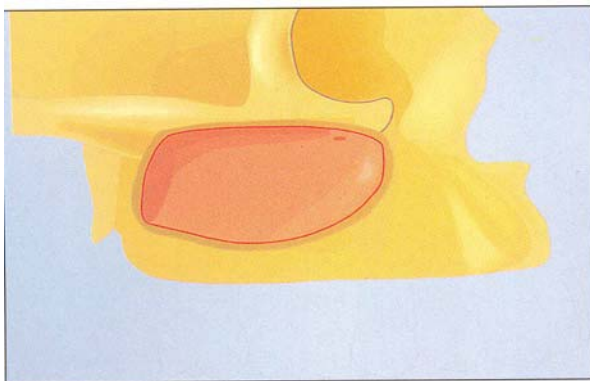
Fig 17 -3e The provisional restoration is shortened about 5 mm at the cervical margin and retrofitted into the four abutment teeth.



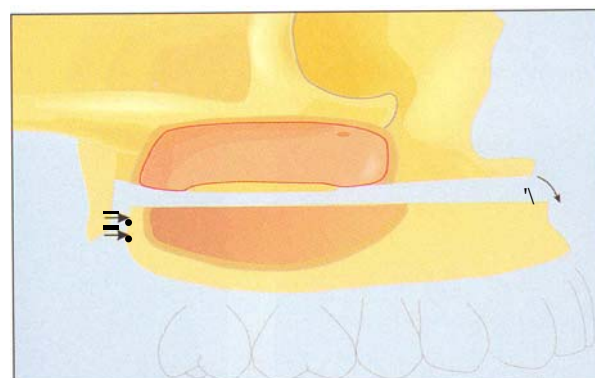
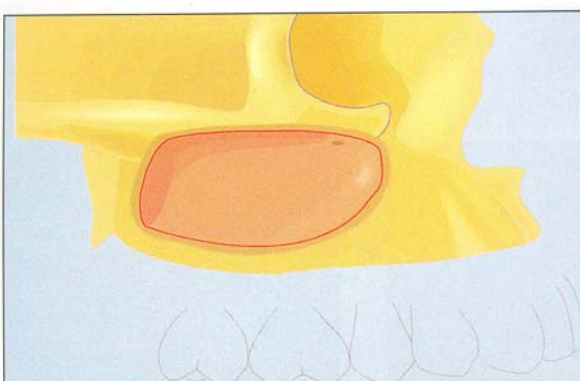
Fig 17-3f The canine abutment teeth are in front of the prosthesis, which is in a proper occlusal relation to the mandibular dentition and the new maxillary alveolar position.



Figs 17 -3g and 17 -3h Comparison of preoperative and postoperative cephalograms.



Figs 17 -4a and 17 -4b Downward and forward movement of the maxilla with sinus grafting. Implants are best placed in a staged approach 6 months after grafting.



Figs 17 -5a and 17 -5b The moderately resorbed maxilla that is commonly in a retrodisplaced position can be freed as a total unit using a horizontal osteotomy cut after sinus membrane elevation.

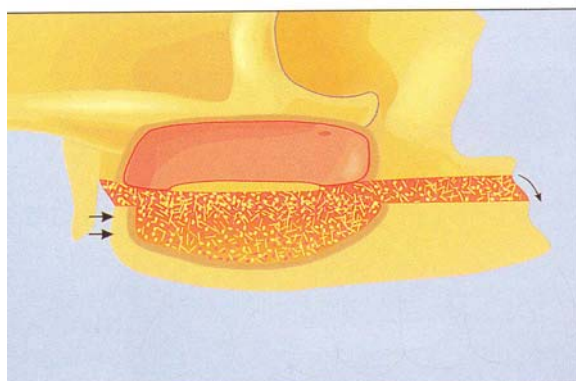


Fig 17 -5c In the advanced maxillary position, fixation and grafting is done to the osteotomy site as well as to the sinus floor.

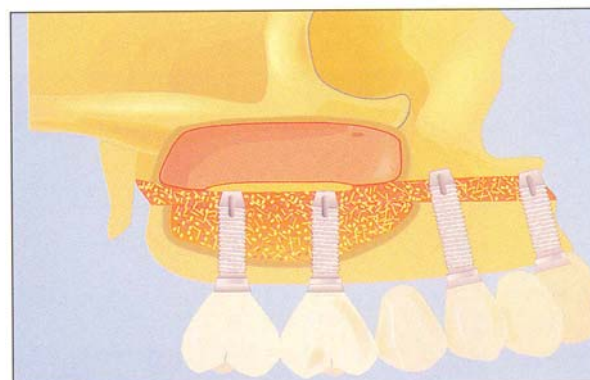


Fig 17 -5d Completion of surgical treatment involves placement of four or five implants in each quadrant according to the prosthetic treatment plan.

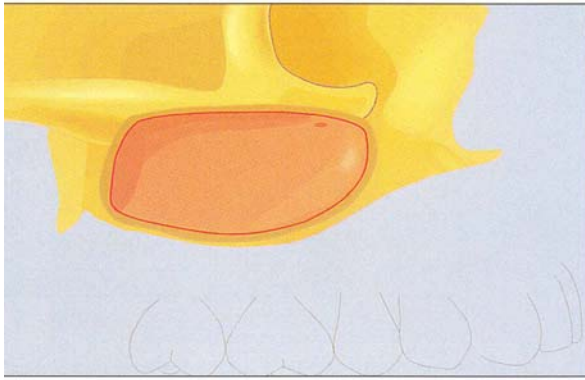


Fig 17-6a In the highly resorbed maxilla, where there is paper-thin bone, the defect involves not only vertical ablation but significant maxillary retrognathia and may involve dehiscence of the nasal floor.

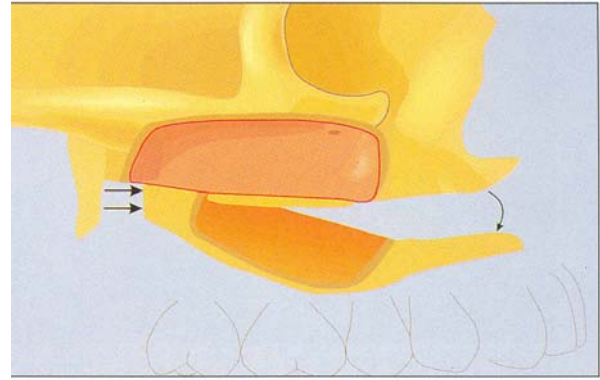


Fig 17-6b The maxilla in this case needs to be downgrafted as well as advanced. Care should be taken to preserve the anterior nasal spine for use as a strut to graft to, if possible.

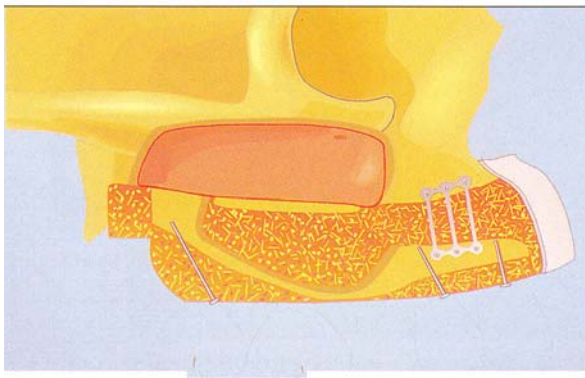


Fig 17-6c Following advancement of the maxilla, lateral fixation is accomplished with resorbable bone plates.

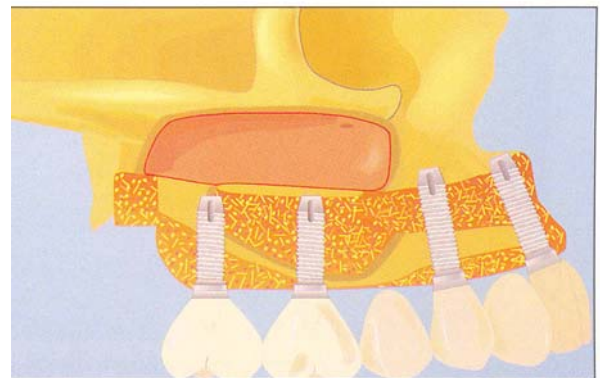


Fig 17-6d Sinus and lateral grafting and barrier membranes can then be used to complete the augmentation. Implant reconstruction follows 6 months later.

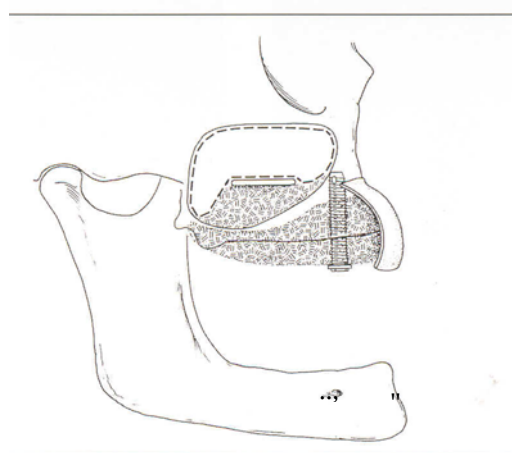
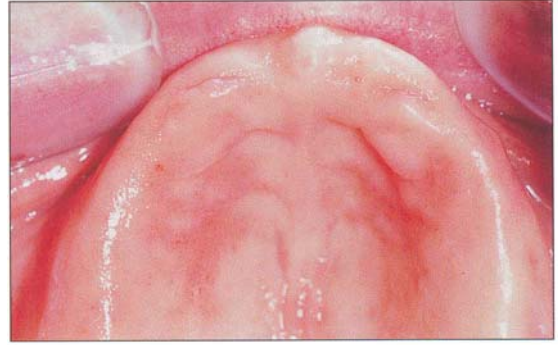
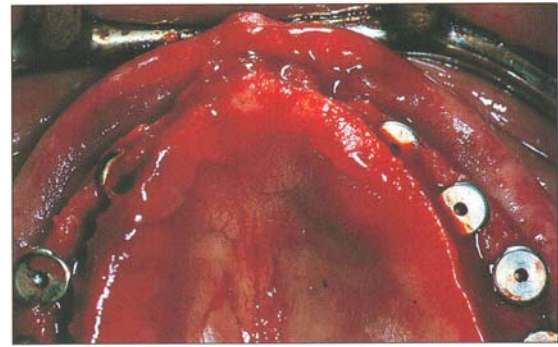
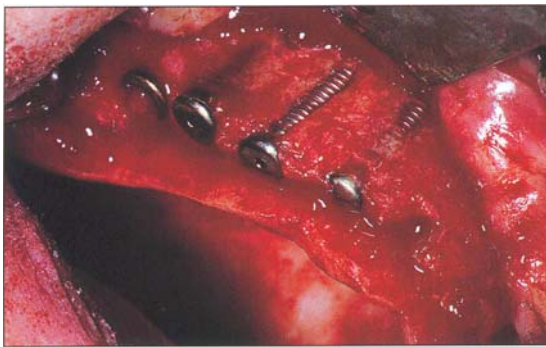


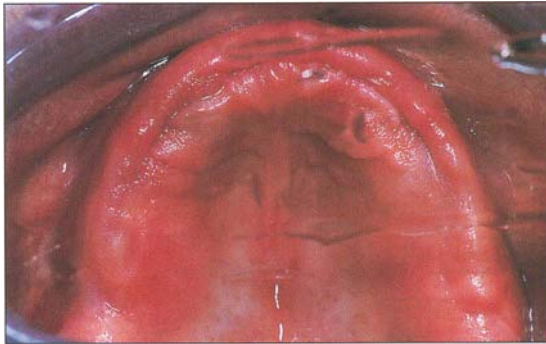
Fig 17 - 7 When there are massive amounts of vertical grafting, complete revascularization of the graft is more difficult and wound dehiscence and graft loss is more likely.



Figs 17 -8a and 17 -8b This 55-year-old patient, who had a complete maxillary denture against a mandibular natural dentition for 22 years, presents with a Class III edentulous maxilla. (Courtesy of Dr Lee Kuhlke.)



Figs 17 -8c and 17 -8d A Le Fort I advancement and lateral and sinus grafting are performed, and posterior implants are placed simultaneously.



Figs 17 -8e and 17 -8f Six months later, the maxilla demonstrates an improved projection, position, and arch form.



Fig 17 -8g The implants are uncovered.

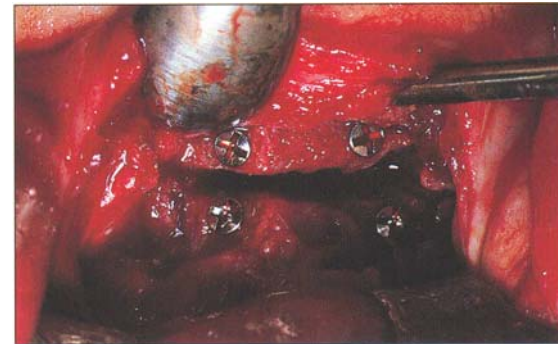
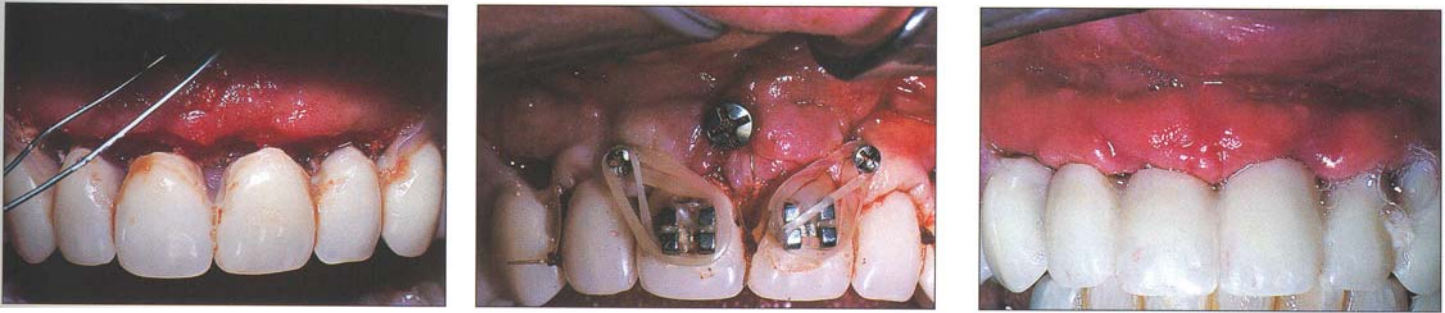
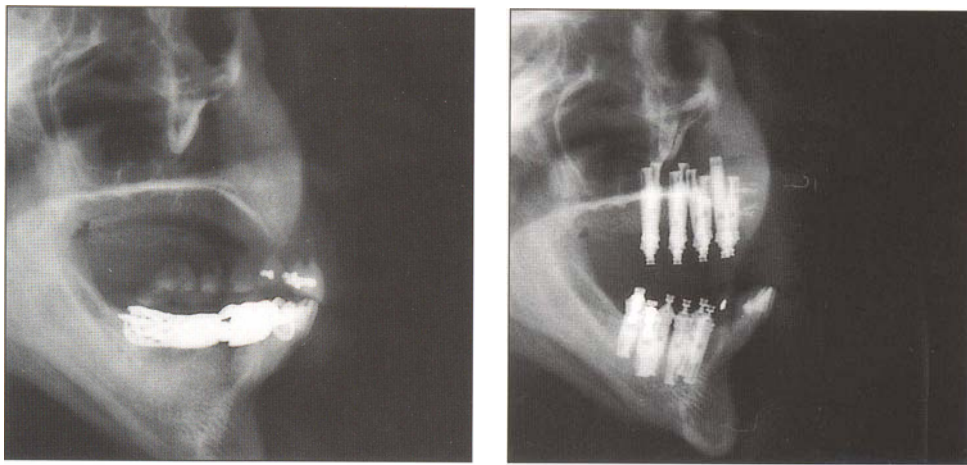


Fig 17 -8h A segmented anterior osteotomy is performed to allow refinement of the ridge using distraction osteogenesis.



Figs 17 -8i to 17 -8k Distraction osteogenesis is used to establish final gingival form in the cosmetic zone. Following the osteotomy, the underside of the provisional is relieved to allow for vertical distraction into the provisional. (Courtesy of Dr Lee Kuhlke.)



Figs 17-8l and 17 -8m Comparison of the preoperative and postoperative cephalograms after distraction osteogenesis.

were performed. Posterior implants were placed simultaneously, but the anterior segment was left edentulous. One year after grafting and implant placement, the now osseous-competent maxilla was refined by an anterior segmental distraction osteogenesis to position the alveolar ridge and to obtain a more ideal gingival form.

Conclusion

The maxilla that has been ablated by years of denture resorption can be more closely reconstructed to an ideal form by using augmentation bone grafting in a combined alveolar, sinus, and LeFort I approach. Ten years of experience with combined alveolar and sinus grafting have shown the results to be stable as long as implants are present and the dental restoration is adequate. The attempt to combine these techniques is also encouraged by the stable history of the Le Fort I procedure in dentate individuals. It is now feasible to combine these techniques and add further refinements such as alveolar distraction in a continued effort to restore form and function to the edentulous maxilla.

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Complications of Maxillary Sinus Augmentation

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Complications associated with maxillary sinus augmentation are uncommon. For the purpose of discussion, these complications have been arbitrarily separated into those occurring intraoperatively, perioperatively, and in the late postoperative period (Table 18-1). The goal of this chapter is to define these complications and discuss their prevention and effective management.

Contraindications to Sinus Augmentation

Appropriate patient selection is paramount to successful sinus augmentation. Patients possessing any contraindication to sinus augmentation should be identified early, and either their condition should be corrected or they should be excluded from this treatment option. Absolute contraindications to sinus grafting include active sinusitis and the presence of maxillary cysts, tumors, or root tips. A history of high-dose, or recent, radiation therapy, uncontrolled diabetes, or an immunosuppressed condition is also a contraindication.

A mucocoele of the maxillary antrum (Fig 18-1) is a relative contraindication, because it predisposes the patient to large membrane perforations during sinus membrane elevation. If a mucocoele is present in the maxillary sinus, it should be removed before sinus augmentation is attempted. This can usually be accomplished by administering local anesthesia along the

Table 18-1 Complications associated with maxillary sinus augmentation

Intraoperative complications

- Membrane perforation
- Fracture of the residual alveolar ridge
- Obstruction of the maxillary ostium
- Hemorrhage
- Damage to adjacent dentition

Early postoperative complications

- Wound dehiscence
- Acute infection
- Implant failure / loss
- Graft loss
- Exposure of barrier membrane

Late postoperative complications

- Graft loss
- Implant loss or failure
- Implant migration
- Oroantral fistula
- Chronic pain
- Chronic sinus disease
- Chronic infection

lateral maxillary wall and then perforating the sinus with a large-bore needle, through which the mucocoele is aspirated. Formal sinus augmentation can then be attempted in 2 to 3 weeks without increased risk of membrane perforation.

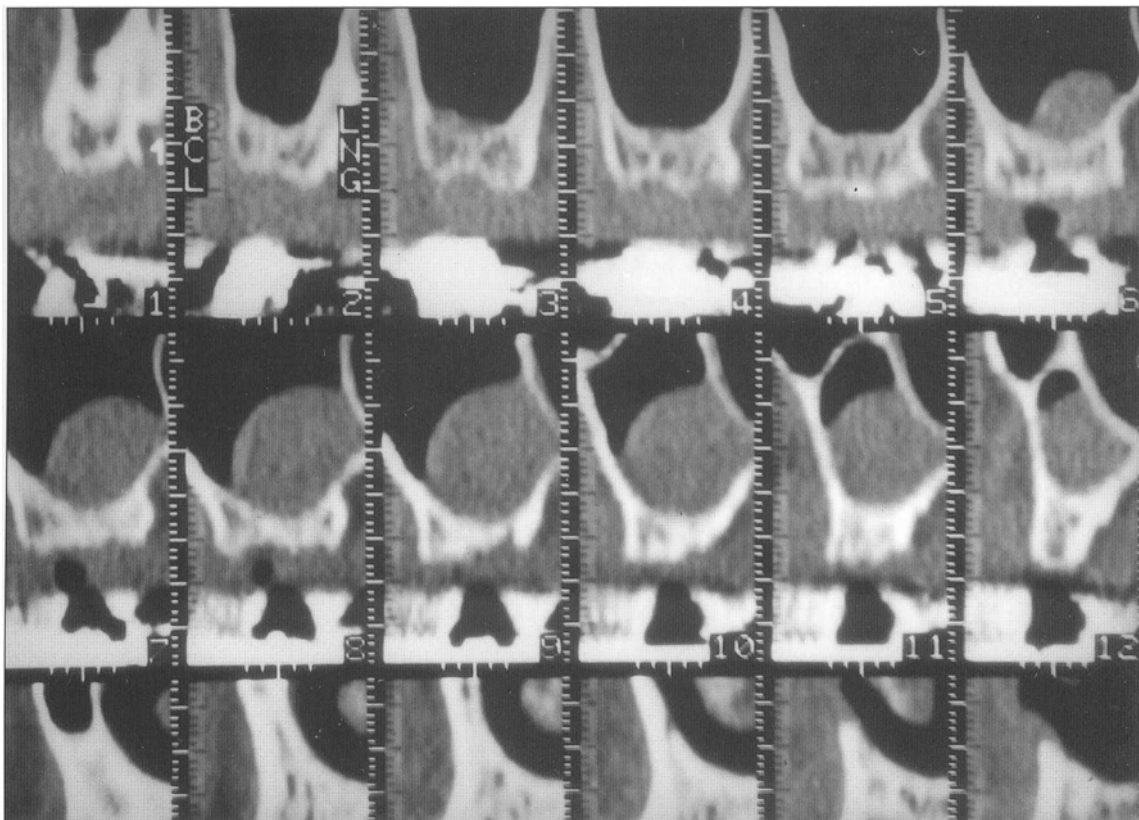


Fig 18-1 The presence of a mucocoele as seen on computerized tomographic (CT) scan. This pathologic entity should be treated prior to sinus augmentation.

Patients with chronic sinus disease resulting from stasis and decreased outflow should also have their condition corrected prior to undergoing sinus augmentation. However, following correction of chronic sinusitis, the sinus membrane remains thickened, often facilitating membrane elevation without perforation.

Patients who smoke should be counseled to cease their habit at least 2 weeks preoperatively.¹ Smoking has been shown to have a negative effect on bone metabolism, which is dose dependent and reversible with smoking cessation.² Unfortunately, the use of nicotine patches has been shown in animal studies³ to inhibit bone healing to a greater degree than smoking. Consequently, the use of transdermal nicotine patches preoperatively and postoperatively may be more counterproductive than allowing the patient to continue to smoke. Small et al⁴ reported infection in two of 45 sinus grafts, consisting of a composite of freeze-dried bone and hydroxyapatite, in patients who were smokers. It is their opinion that heavy smoking (not defined) is an absolute contraindication to this procedure.

Inappropriate treatment planning can also lead to complications following sinus augmentation. Preoperative evaluation of the magnitude of the maxillomandibular space is critical to avoid insufficient restorative space, or an excessive crown-root ratio in the final restoration. In patients with an excessive maxillomandibular distance, consideration should be given

to only bone grafting in conjunction with, or in place of, sinus augmentation. As with any procedure, appropriate informed consent must be obtained (Fig 18-2).

Intraoperative Complications of Sinus Augmentation

Regardless of the specific technique used during sinus augmentation, the goal of surgery is to dissect the schneiderian membrane superiorly to allow grafting of the inferior aspect of the maxillary antrum. It is generally agreed that every effort should be made to minimize membrane perforation. However, this is not always possible, because of membrane or antral anatomy. The schneiderian membrane is composed of periosteum covered by respiratory epithelium, which is extremely thin, friable, and easily perforated (Fig 18-3).

The presence of sinus septa can hinder elevation of the membrane (Fig 18-4) and increase the likelihood of perforation. The location of septa should be identified preoperatively by transillumination and correlated with radiographic findings (plain or computerized tomography). Other diagnostic clinical tests that may be used to confirm the presence and location of septa include direct inspection, gentle percussion with a metal instrument, and digital compression of the antral wall.

When a septum is present, additional steps are required to prevent membrane perforations. Either the septum can be osteotomized along the sinus floor, or two antral openings can be created, one on either side of the septum. Because the septa are often located in areas critical to implant placement, osteotomy or performance of the two-antral window technique is often necessary.

Management of membrane perforations is not clearly defined in the literature; however, two critical actions are necessary. First, the membrane must be elevated or removed from the antral floor. This is critical because placement of grafting material on top of any unelevated membrane would prevent osseous incorporation of the graft and predispose the graft to infection.

You are going to have a sinus augmentation procedure. Therefore, you or your guardian should understand the nature of the operation and the most common risks involved. Surgery is not an exact science, and this consent form does not list all of the possible complications that can be associated with this procedure. In addition, the surgeon cannot guarantee the results of the sinus augmentation procedure(s).

The surgical procedure requires incision and reflection of the tissues (gums), removal of bone to expose the sinus cavity, lifting of the sinus membrane, placement of a bone graft into the floor of the sinus, possible placement of a barrier membrane, and closure of the wound with stitches. Implants may or may not be placed at the same time as the sinus lift procedure.

This operation will be followed by a degree of discomfort, swelling, nasal and/or sinus stuffiness, and pain that will require 5 to 10 days of recuperation. Complete resolution of all symptoms may take 3 weeks or longer.

Possible complications of this procedure include:

- Wound infection, sinus infection
- Pain
- Postoperative bleeding, nosebleed
- Soreness of the corners of the mouth
- Discoloration (black and blue) of the face or jaws
- Temporary or permanent numbness of the gums, upper teeth, and palate in the area of the procedure
- Loss of the bone graft
- Exposure of the barrier membrane, requiring another procedure for its removal
- Development of an opening between the sinus and the mouth
- Damage to teeth or fillings; loss of teeth
- Inability to place implants in the bone graft in the future
- Development or worsening of jaw joint symptoms
- Need for additional surgery
- Other _____

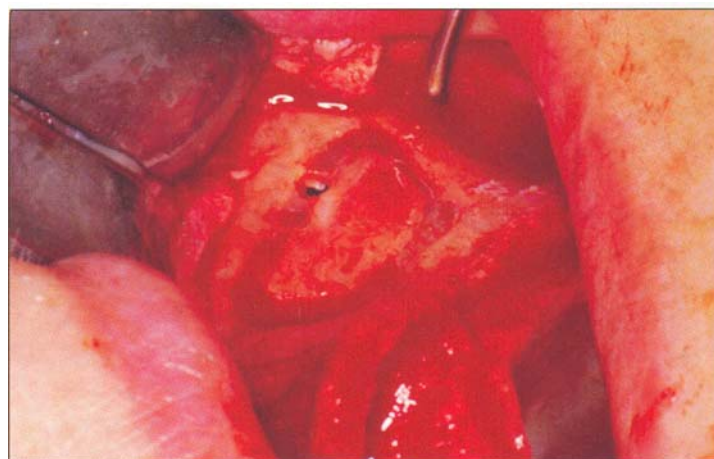


Fig 18-3 Small perforation, located superiorly, made inadvertently by rotary instrumentation. This perforation can be managed by conservative measures, as described in the text.

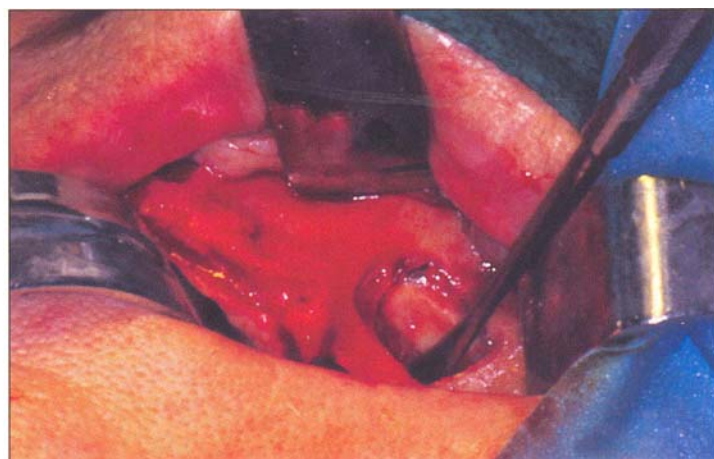


Fig 18-4 Sinus septa being osteotomized along the antral floor to enable lifting of the entire membrane for augmentation.

Fig 18-2 Patient consent form for sinus augmentation.



Fig 18-5 Collagen membrane, commonly used to cover small-to-medium membrane perforations.

or failure. Second, any hole in the membrane must be closed to prevent extrusion of particulate grafting material into the mucosal envelope of the sinus.

It is not possible to physically repair the torn membrane itself because of its thin and fragile nature. Small perforations are easily managed without intervention, because, as the membrane is elevated, it folds on itself. Gelatin film or a collagen membrane (Fig 18-5) is recommended for management of perforations less than 5 mm in diameter.

Perforations greater than 5 mm pose a different problem. Large membrane perforations can allow spreading of bone fragments within the sinus, leading to inflammation or infection, especially if particulate grafting material is used. Triplett and Schow⁶ recommended the use of a block graft rather than a particulate graft when perforations larger than 5 mm occur. Keller et al⁷ agreed and stated that an intact membrane is not critical for the corticocancellous block grafting technique, unlike the particulate grafting procedure, where the membrane is necessary to control graft position. Raghoobar et al⁸ lent some scientific support to this conclusion by reporting no unfavorable sequelae in eight membrane perforations of a series of 47 sinus augmentations, when a superior cortical bone graft was combined with cancellous particulate graft below.

Other authors believe that membrane perforation is not a problem. Jensen et al⁹ reported that, despite a 35% incidence of sinus membrane perforations at the time of surgery, no signs of infection were noted in any patient. In every case, consolidation of the remaining graft allowed for subsequent implantation. McKenna¹⁰ concluded that the antral membrane serves no role in the containment of the bone graft during either the corticocancellous or cancellous technique. He described a technique in which the cancellous bone is placed incrementally on the antral floor using a periosteal elevator as a superior stop against which the graft is condensed. The thin antral membrane is then draped over the con-

densed bone and congealed blood, serving no mechanical function.

In summary, it would appear that it is preferable to prevent antral perforations if possible; however, small perforations would not prevent grafting if appropriately managed. It is our preference to use particulate cancellous grafts that are precompressed in a syringe and then injected into the sinus, as described by McKenna.¹⁰ It is our belief that large perforations should be managed by either use of a corticocancellous graft with or without cancellous bone along the antral floor, or abandonment of the procedure.

Heavy bleeding may occur during the exposure and isolation of the sinus membrane, especially if perforation occurs. Occasionally, large vessels are encountered within the maxillary bone. The use of a round diamond bur with copious irrigation and a gentle brushstroke technique enables the operator to keep the field clean and to directly visualize any vessels and the membrane. The vessel can then be treated appropriately, ie, cauterized. A diamond bur (in contrast to a fluted bur) decreases the chance of membrane perforation, because it tends to displace the membrane rather than grab and tear it.

Care must be taken when the surgeon is working in proximity to the dentition. An excessively large antral opening can devitalize adjacent teeth or reduce the bony support of the adjacent natural dentition. Patients must be informed regarding dental injury and the possibility of dental loss or the need for endodontic therapy with subsequent restoration.

A final intraoperative complication is a lack of primary implant stabilization when simultaneous sinus augmentation and implant placement are attempted (Figs 18-6a to 18-6c). Implants can be placed simultaneously with sinus grafts provided that adequate, nonmobile alveolar bone is available to stabilize the implants. Simultaneous sinus augmentation and implant placement can stimulate a coordinated consolidation of the graft around the implants when at least 5 mm of residual alveolar bone is available. This amount of bone will prevent migration or even loss of implants during the early healing phase.¹¹

If implants are not stabilized by the existing alveolar ridge, they should be removed and replaced as a secondary procedure. Fracture of the residual alveolar ridge during sinus augmentation or when implant sites are prepared would also mandate secondary implantation after graft consolidation. A two-stage procedure allows the bone graft to heal and consolidate prior to the placement of implants. The use of particulate bone grafts contributes to the effectiveness of this procedure, because particulate grafts can revascularize in as early as 2 weeks, unlike corticocancellous grafts, which can take up to 4 months.¹²

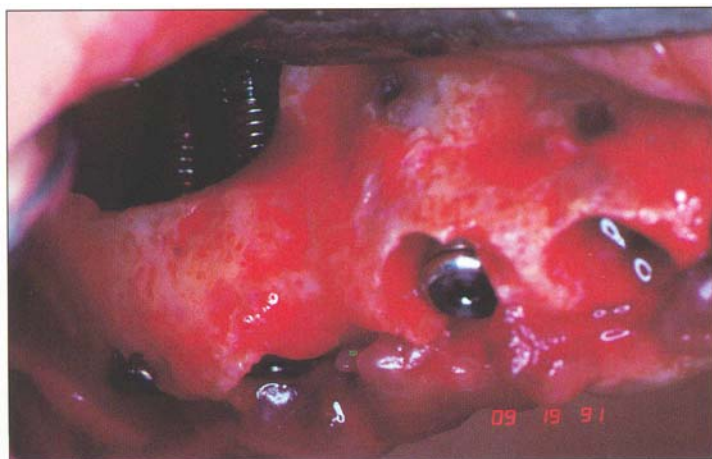


Fig 18-6a Patient who was treated with extractions, immediate implant placement, and simultaneous antral augmentation with autologous bone. There is a minimal amount of bone available for the primary stabilization of the implants.

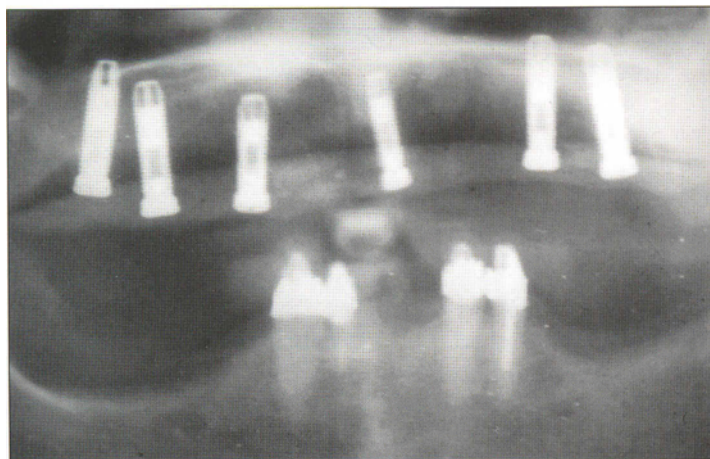


Fig 18-6b Postoperative panoramic radiograph of the patient in Fig 18-6a. Note the small amount of ridge height available for primary implant stabilization.

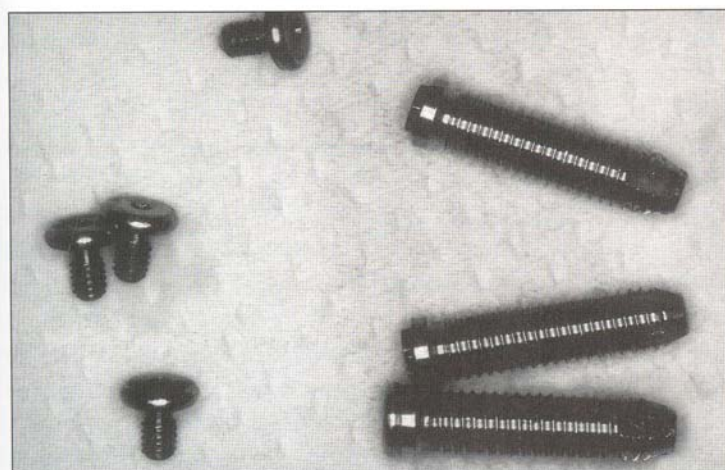


Fig 18-6c Loss of three right implants, which were loose and spontaneously exfoliated from the surgical site.

Early Postoperative Complications of Sinus Augmentation

Prevention is the best treatment for early complications. Therefore, many surgeons advocate the use of antibiotics, nasal decongestants, and sinus precautions following sinus augmentation. Sinus precautions include avoidance of any action that creates positive or negative sinus pressures, such as drinking through a straw (which creates a negative intrasinus pressure); cessation of nose blowing for at least 2 weeks; and sneezing with an open mouth to decrease internal antral pressures. Any positive pressure could spread air through confluent soft tissue planes, creating a soft tissue emphysema.

Block and Kent¹³ reported a case in which a graft was lost in a patient who blew her nose on the second postoperative day. Normal sinuses can produce up to 2 L of fluid per day; thus, decongestants and topical vasoconstrictive agents are useful in promoting normal drainage.

A common early complication is breakdown of the incision line or overlying tissue. Again, prevention is the best method of treatment for wound breakdown. Good surgical technique dictates wound closure over intact bone without tension. Undermining of flaps, scoring of the periosteum, or extension of the incision into the vestibule may be required to achieve passive wound closure. Patients should be instructed not to wear any prosthesis over the site until the mucosal incision has closed completely (approximately 2 weeks). In addition, a soft diet should be maintained for the same period of time.

Small wound dehiscences can be managed with saline or chlorhexidine irrigation and rinses. Any prosthesis should be relieved in the area of the wound breakdown, or the patient should be instructed not to wear the prosthesis until wound closure is achieved. In these cases, healing usually occurs by secondary intention.

The premature exposure of a barrier membrane necessitates its removal, because it may act as a conduit for bacterial contamination, resulting in subsequent loss of graft and/or implants (Fig 18-7). If large areas of the graft are exposed, the graft may have to be debrided back to attached bleeding tissue or totally removed. In this case, the antral membrane should be inspected for tears or perforations. If there are no large membrane defects, the wound can be reapproximated and the sinus augmentation repeated in 2 to 3 months.

A large membrane tear, with or without oroantral communication, requires management by standard surgical techniques for the treatment of oroantral fistulas. The sinuses should be followed both clinically and radiographically prior to any regrafting procedure.

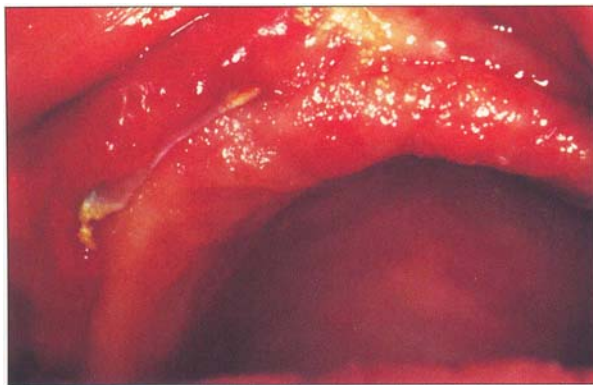


Fig 18-7 Exposure of a barrier membrane. This membrane was removed because the entire edge of the membrane was exposed.



Fig 18-8a Axial CT scan demonstrating a postoperative infection in a patient who previously underwent bilateral sinus augmentation. Total obliteration of the left antrum has resulted from the infectious process, with some loose particulate bone present.

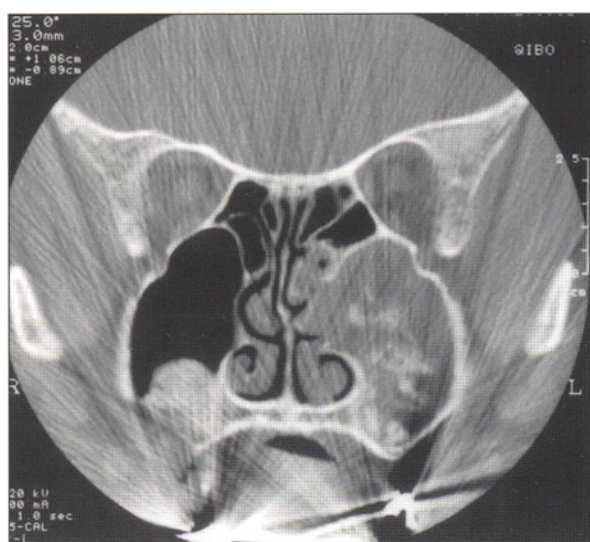


Fig 18-8b Coronal view of the patient in Fig 18-8a, demonstrating the complete obliteration of the left antrum by the infection. The right sinus augmentation illustrates the proper height of grafting, in which the ostium is patent to allow for normal drainage. Note the escape of particulate grafting material into the sinus.

ture. In this case, a healing period of 6 months or more is recommended.¹⁴

Any blockage of the ostium or disturbance of the mucociliary action can lead to failure to clear secretions and bacteria from the sinus, resulting in an infection (Figs 18-8a and 18-8b). A positive correlation between preoperative sinus disease and the development of acute sinusitis following sinus augmentation has been demonstrated.¹⁵ It is prudent to evaluate patients with a history of sinusitis radiographically to rule out obstructive disease, which could be exacerbated by the inflammation produced by the sinus graft augmentation.

Maintenance of normal maxillary sinus physiology and ostium patency is critical to the success of this procedure; therefore, the surgeon should not fill the entire sinus with the graft material. Instead, it is mandatory to keep the augmentation below the level of the ostium. As a rule of thumb, the surgeon should limit augmentation to less than 2.5 cm above the floor of the antrum (depending on the degree of pneumatization). Sinus symptoms that persist despite antibiotic and decongestant therapy require further imaging and possible surgical exploration.¹⁶ Additional surgical intervention will almost certainly compromise any sinus graft and/or implants.

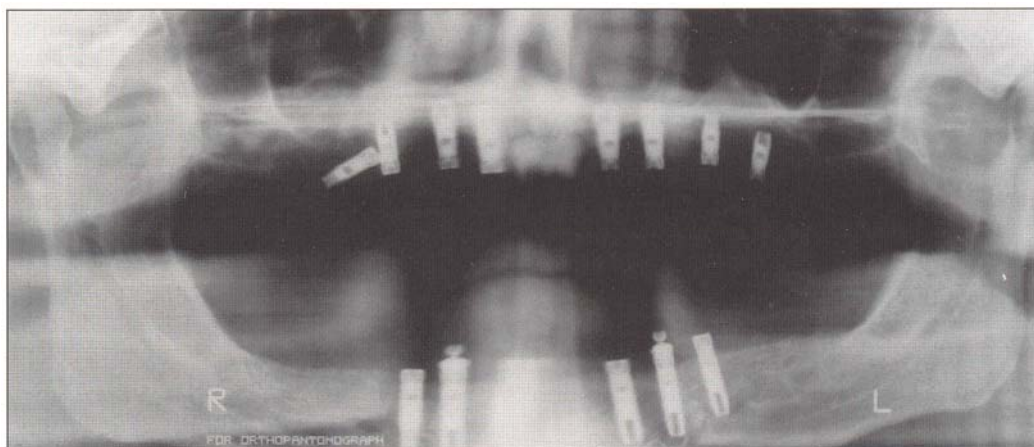


Fig 18-9 Postoperative panoramic radiograph of a patient who underwent bilateral sinus augmentation and secondary maxillary implant placement. Prior to second-stage implant surgery, the radiograph demonstrated the loss of the maxillary right posterior implant. Bone loss in the augmented area led to the implant failure.

Late Postoperative Complications of Sinus Augmentation

Rehabilitation of the maxilla with an implant-retained prosthesis is usually the final goal of sinus augmentation. For patients who are not candidates for primary implant placement, the optimal waiting period for secondary implant placement is dictated by the graft material utilized. Autogenous bone grafts can be implanted in 3 to 6 months, whereas alloplastic materials may take up to 18 months for graft consolidation. Mixtures of alloplastic and autologous or allogeneic and autologous materials can require up to 12 months for adequate ossification and consolidation prior to implant placement.

Overall, implant placement following sinus augmentation is a predictable and reliable technique for reconstruction of the posterior atrophic maxilla. Implant osseointegration relates to the final stability of the implant within bone, because there is no agreed on histologic definition for this phenomenon.¹² Using this description, implant losses have been reported to varying degrees, depending on the implant staging, augmentation technique, and grafting materials used (Fig 18-9). Blomqvist et al reported an 18% implant failure rate in primary implantation cases using a corticocancellous inlay block technique. Misch and Dietrich⁹ reported a failure rate of 1 % in secondary implantation cases and 10% in primary implantation cases. Wheeler et al¹⁰ reported a 5% failure rate for primary and secondary implant cases combined.

Implant failure often mandates an additional healing period followed by reimplantation and possibly an additional bony augmentation procedure. If implants are lost, the surgeon should assess whether an oroantral commu-

nication is present, and, if so, take appropriate steps for closure. The extent of bone loss should also be assessed and a determination should be made about the suitability of the remaining bone for implant placement. If inadequate bone remains, the patient should be regrafted.

HalF¹ noted that failure of implants most often occurred at the time of abutment placement or within the first 3 weeks following uncovering. To prevent implant failure, it has been suggested that progressive implant loading should be employed to convert less mineralized bone into bone more capable of bearing masticatory forces.²² For patients experiencing chronic pain after implant placement and loading, consideration should be given to removal of the implant with a trephine bur or temporary unloading of the implant. If infection and chronic pain are associated with an implant, the possible presence of infection should be considered and appropriate therapy should be initiated.²³

Conclusion

Sinus augmentation requires a significant investment of time and finances from both the surgeon and patient. Appropriate candidate selection, treatment planning, and surgical technique are critical to success. Sinus augmentation is not without complications; the surgeon must be able to manage problems that arise intraoperatively as well as those that develop in the early and late postoperative periods. Implants can be placed simultaneously, if adequate stabilization can be obtained, or as a secondary procedure after graft consolidation. If properly planned and performed, implant placement in conjunction with sinus augmentation of the atrophic posterior maxilla is a predictable and reliable technique.

A Consensus Conference on the Sinus Graft

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A consensus conference was organized under the auspices of the Academy of Osseointegration to ascertain the efficacy and safety of the sinus bone-grafting procedure. It was held at Babson College, Wellesley, Massachusetts, on November 16 and 17, 1996. This chapter summarizes the proceedings of the conference.¹

The sinus graft (previously termed *sinus lift*) was introduced by Boyne et al² and Tatum³ in 1985 and 1986, respectively. It is a relatively new procedure, being used with increasing frequency, but without documented prospective clinical trials. The sinus graft is performed with some procedural variations and many different materials, but at present there is no scientific basis for choosing from among these options. A literature review using meta-analysis, presented at this conference, revealed only a few case series with adequate numbers of patients and follow-up. Given this paucity of satisfactory research, consensus methodology appeared quite appropriate at this juncture for studying the benefit and risk of the sinus graft and the myriad of materials and material combinations in use for this procedure.³

¹ The complete text of these proceedings has been published in *The International Journal of Oral & Maxillofacial Implants* (1998;13[suppl]).

Methods and Materials

Data

The Sinus Graft Consensus Conference offered a means for accessing a much larger database than that available in the literature by tapping the more extensive experience, insights, and judgments of oral surgeons, prosthodontists, and dentists from throughout the world. To this end, all first authors of published articles, as well as many clinicians known internationally to be actively performing this surgical procedure or its related prosthodontics, were invited to submit data on the sinus graft.

Data on uniform consecutive case series ongoing for at least 3 years were requested; the material submitted was to include radiographs at significant points in the implant restoration sequence. Only cases in which root-form implants were used were accepted. Data forms (see next page) were mailed to those accepting the invitation. Bone and implant survival were the primary indicators of graft success. The data were analyzed by the designated conference statistician. Thirty-eight clinicians furnished data on 1,000 cases, including more than 3,500 implants,

ACADEMY OF OSSEOINTEGRATION SINUS GRAFT CONSENSUS DATA FORM

[illegible]

PROCEDURE: (check and circle appropriate variables)

☐ Sinus Graft Only: ■ R ■ L ☐ Nasal Lift Only: ■ R ■ L ☐ Both: ■ R ■ L

☐ Membrane Tear: ■ R ■ L Repaired? ■ R ■ L

☐ Membrane Repair: ■ Suture (Type: _____)

 ■ Collagen (Type: _____)

 ■ Autograft (Type: _____)

 ■ Lambone ■ Other _____

☐ Procedure Aborted: (irreparable tear) ■ Y ■ N

PRE-OP SINUS CONDITION: (check appropriate variables)

☐ Healthy ☐ Previous Sinus Surgery ☐ Cysts

☐ Thickening ☐ Ongoing Sinusitis

RISK FACTORS: (check and circle appropriate variables)

☐ Post-menopausal: ■ w/ Estrogen ■ w/o Estrogen
☐ Chronic Steroid Therapy
☐ Significant Cardiovascular Disease
☐ Radiation to Maxilla
☐ Smoker: ■ Current ■ Discontinued # _____ Weeks
☐ Diabetes: ■ Controlled ■ Uncontrolled
☐ Chemotherapy
☐ NONE OF THE ABOVE

MATERIAL: (check and circle appropriate variables and complete blanks)

☐ Autograft: Type: ☐ Cortical ☐ Cancellous ☐ Cortical/Cancellous

MATERIAL: (continued)

☐ **Allograft:**

- ☐ Cortical ☐ Cancellous ☐ Cortical/Cancellous
- ☐ Particle Range (microns) _____
- ☐ Demineralized Freeze-dried Bone
- ☐ Freeze-dried Mineralized Bone
- ☐ Frozen-Irradiated (not freeze-dried)
- ☐ Tissue Bank _____

☐ **Xenograft:** ☐ Bio-Oss ☐ Other: _____

☐ **Alloplast:** ☐ HA (Source/Type _____) ☐ TCP

☐ **Other:** _____

☐ **Composite Ratio:** Auto _____% Allograft _____%
Xeno _____% Alloplastic _____%

TECHNIQUE: (check appropriate variables)

☐ Lateral Window ☐ Alveolar ☐ Sandwich
☐ LeFort I ☐ Pterygoid ☐ Other: _____

TIMING OF IMPLANT PLACEMENT: (check appropriate variable)

☐ Simultaneous

☐ Delayed

How long: _____

SUPERSTRUCTURE: (check and circle appropriate variables and complete blanks: please indicate right or left side or both for each factor below)

☐ Implant-Retained (rigid/fixed) ☐ Implants Stabilized (tissue borne/removable)

Support Units

Support Units	Number of Sinus Implants
of each Prosthesis:	Number of Non-Sinus Implants

PATIENT: Last Name: _____ F.I. _____ M.I. _____ M _____ F _____ AGE _____ SURGEON: _____ Last Name: _____ F.I. _____ M.I. _____

IMPLANT DATA: (one site only) Site # _____ Brand: _____ Length: _____ mm Diameter: _____ mm
Surface: ☐ Smooth Ti ☐ Plasma Spray Ti ☐ HA ☐ Other: _____ Geometry: ☐ Screw ☐ Cylinder

PHASE	DATE	BONE		IMPLANT					PERI-IMPLANT MORBIDITY			
		Height mm*	Bone Loss mm	Implant Removal or Loss	Implant Mobility	Continuous Bridge Function	Pain	Infection	Bleeding on Probing	Exudate on Probing		
	mm/dd/yy		Crestal Apical	Y • N • NA	Y • N • NA	Y • N • NA	Y • N • NA	Y • N • NA	Y • N • NA	Y • N • NA		
Residual Ridge (pre-graft)	/ /											
Sinus Graft**	/ /											
Implant Placement	/ /											
Abutment Connection**	/ /			Φ								
Restoration	/ /											
Year 1	/ /											
Year 2	/ /											
Year 3** or within 6 months	/ /											
Most Recent Exam** ____ Yr	/ /											

* X-RAYS TO BE READ BY COMMITTEE RADIOLOGIST

** SUBMIT BEST RADIOGRAPHS (PA; PAN; OR CT)

Implant Replaced: Y N Date: _____

Post-Operative Sinus Condition: ☐ Healthy ☐ Bleeding ☐ Infection ☐ Fistula ☐ Other (please specify): _____

☐ FOR RADIOLOGIST USE ONLY

☐ NOT APPLICABLE

Last Date Observed: _____

Intact: Y N

F = BONE NOT SUITABLE FOR PLACEMENT

Y = Yes N = No NA = Not Applicable

Intact: Y N

IMPLANT DATA: (one site only) Site # _____ Brand: _____ Length: _____ mm Diameter: _____ mm
Surface: ☐ Smooth Ti ☐ Plasma Spray Ti ☐ HA ☐ Other: _____ Geometry: ☐ Screw ☐ Cylinder

PHASE	DATE	BONE		IMPLANT					PERI-IMPLANT MORBIDITY				
		Height mm*	Bone Loss mm		Implant Removal or Loss	Implant Mobility	Continuous Bridge Function	Pain	Infection	Bleeding on Probing	Exudate on Probing		
			Crestal	Apical									
	mm/dd/yy												
Residual Ridge (pre-graft)	/ /												
Sinus Graft**	/ /												
Implant Placement	/ /												
Abutment Connection**	/ /												
Restoration	/ /			Φ									
Year 1	/ /												
Year 2	/ /												
Year 3** or within 6 months	/ /												
Most Recent Exam**	/ /												
_____Yr	/ /												

* X-RAYS TO BE READ BY COMMITTEE RADIOLOGIST

** SUBMIT BEST RADIOGRAPHS (PA; PAN; OR CT)

Implant Replaced: Y N Date: _____

Post-Operative Sinus Condition: ☐ Healthy ☐ Bleeding ☐ Infection ☐ Fistula ☐ Other (please specify): _____

☐ FOR RADIOLOGIST USE ONLY

☐ NOT APPLICABLE

Last Date Observed: _____

Intact: Y N

F = BONE NOT SUITABLE FOR PLACEMENT

Y = Yes N = No NA = Not Applicable

Intact: Y N

Objectives

The primary objectives of this consensus meeting embraced six basic questions:

1. Does sinus grafting enable implants to function in the posterior maxilla for reasonable lengths of time?
2. What are the indications and contra indications for sinus grafting?
3. Do the various materials in use for the sinus graft differ in performance? If so, how do they differ?
4. What are the comparative success rates for the materials used in sinus grafting, and what do we know about their outcome determinants?
5. How do simultaneous and delayed implants compare in sinus grafting cases?
 6. Which prosthodontic variables are relevant to sinus graft efficacy and how do they effect implant integration and long-term function?

Presentations

The consensus conference agenda (see Appendix, page 228) indicates a broad representation of participants offering data and/or formal presentations.

Radiographic analysis

A radiographic analysis was performed on a subset of cases, wherein bone loss was measurable, to assess the fate of sinus grafts themselves over a 3-year period. The effects of smoking, the type of graft material, and residual bone height were considered. Of the 900 patients screened, only 100 qualified for representative radiographic analysis. In these 100 patients, 145 sinus grafts containing 349 implants were studied. Nine grafting materials and material combinations were represented in this group.

The regions of interest in panoramic radiographs were digitized using Periovision software developed at the University of Alabama. The Periovision postoperative bone height, both residual and replacement, was measured and calculated using a conversion factor adjusted for magnification error.^{4,5} The initial measurement is expressed in millimeters per pixel, using the actual size of the proximate implant divided by the implant length in pixels measured on the digitized panoramic radiograph.⁶ This conversion factor for each sinus graft yields the most accuracy obtainable from a panoramic radiograph. The Periovision software enables bone height to be expressed directly in millimeters.

On the preoperative panoramic radiograph (no implants), the amount of residual bone was quantified

using a standard conversion factor of 25% for magnification. Sites were stratified into three groups: (1) less than 4 mm, (2) between 4 and 8 mm, and (3) more than 8mm.

Sinus graft height was measured at each implant site on all panoramic radiographs. As stated, the actual length of an implant in the field furnished a reference standard. To evaluate progressive changes in the graft, analyses were repeated on each successive follow-up radiograph. When an implant was no longer present on the follow-up radiograph, the implant was recorded as lost.

Statistical analysis

Analysis of variance models were constructed to compare mean graft loss with (1) graft type (material and form), (2) residual bone height, (3) implant surface, and (4) smoking status. Planned comparisons with post-hoc tests, based on the difference in means, were performed. Patients were not included in the analysis of effects for which data were missing.

Results

The primary indicator for graft success was percent year implant survival (eg, 90% 3-year survival). Data forms on 3,554 implants were completed by 38 surgeons. Of these implants, 2,449 were placed prior to January 1, 1994, and 905 were placed after that date. The frequency of cases per surgeon is listed in Table 191. Life-table analysis yielded an overall implant success rate of 90% at 3 to 5 years.

Material analysis

Table 19-2 summarizes the results for all sinus grafting materials: autograft (self), allograft (other individual), xenograft (other species), alloplast (artificial material), and their combinations.

Autografts

Autogenous bone was used as a graft in particulate or block form. Autografts were used alone or combined with allograft, xenograft, or alloplast (see Table 19-2). For those areas grafted with autogenous bone alone, there was a cumulative implant survival rate of 86% at 5 to 6 years (Table 19-3). The addition of allograft decreased the rate to 79%. Three other combinations are shown in Table 19-2 with their representative implant survival rates.

Table 19-1 Number of sinus grafting cases per surgeon

No. of cases	No. of surgeons
1-10	8
11-20	11
21-35	12
36-104	9

Table 19-2 Implant survival by sinus grafting material (life-table analysis)

Graft materials	No. of implants	3 years	5 years
AP	163	98%	98%
AP + X	125	98%	98%
AL	254	85%	85%
AL + X	199	80%	
AL+AP	563	93%	90%
AU (particulate)	264	93%	90%
AU + AP	331	91%	90%
AU + AL	124	82%	
AU + AL + X	306	96%	
AU + AL + AP	205	93%	93%

AP = alloplast; X = xenograft; AL = allograft; AU = autograft.

Table 19-3 Implant survival in pure autografts (life-table analysis)

Year	No.	Failed	Survival	SE
0-1	544	40	0.926	0.011
1-2	440	5	0.916	0.012
2-3	357	7	0.898	0.014
3-4	266	0	0.898	0.014
4-5	171	2	0.887	0.015
5-6	100	3	0.861	0.021
6-7	59	1	0.846	0.025

Particulate autograft alone was used in 118 procedures. Forty-three autografts were used in block form, and 35 grafts combined particulate and block forms. Of these autografts, most were from the hip; a fair number were from the chin, and a few were from other sources. There was no statistically significant difference between particulate and block forms of autografts (logrank: $P > .389$; Wilcoxon: $P > .401$).

For the pure autograft group when implant design was specified, 123 implants were cylinders and 454 were screws. Of the 577 implants in the pure autograft group, 66.7% were smooth surfaced, 9.8% were plasma sprayed, and 20.6% were hydroxyapatite coated. The effect of implant surface on autograft effi

cacy is shown in Tables 19-4 to 19-7. There was a statistically significant difference (10%) between the smooth and roughened surfaces (log-rank: $P < .001$; Wilcoxon: $P < .004$).

A life-table analysis was performed to compare implants placed simultaneously with the autogenous sinus grafts and implants delayed for bone healing. One hundred seven procedures were delayed and 121 were simultaneous. There was an 85% 5-year survival rate for implants placed immediately and an 89% 5-year survival for implants placed subsequent to bone autograft placement. There was no significant difference in cumulative success rates between these two groups (logrank: $P > .064$; Wilcoxon: $P > .997$).

Table 19-4 Implant survival in autografts by type of implant surface

Implant surface	No.	Failed	Survival	SE
Smooth	95	0	86%	2%
Plasma-sprayed	21	0	97%	2%
Hydroxyapatite-coated	54	2	95%	3%

Table 19-5 Survival of smooth-surface implants in bone autograft (life-table analysis)

Year	No.	Failed	Survival	SE
0-1	366	38	0.896	0.016
1-2	275	5	0.880	0.017
2-3	208	6	0.855	0.020
3-4	144	0	0.855	0.020
4-5	95	0	0.885	0.020
5-6	57	2	0.825	0.028

Table 19-6 Survival of plasma-sprayed implants in bone autograft (lifetable analysis)

Year	No.	Failed	Survival	SE
0-1	60	2	0.967	0.023
1-2	58	0	0.967	0.023
2-3	54	0	0.967	0.023
3-4	42	0	0.967	0.023
4-5	21	0	0.967	0.023
5-6	8	1	0.853	0.109

Table 19-7 Hydroxyapatite-coated implants in bone autograft (life-table analysis)

Year	No.	Failed	Survival	SE
0-1	112	0	1.00	0.000
1-2	105	0	1.00	0.000
2-3	94	1	0.989	0.010
3-4	79	0	0.989	0.010
4-5	54	2	0.953	0.027
5-6	34	0	0.953	0.027

Allografts

Bone allografts were used alone and in combination with other graft materials. A life-table analysis indicated an 85% cumulative success rate for implants placed in sinus allografts. Life-table analyses were also performed for different forms of allografts. Frozen irradiated allografts had a significantly lower implant survival rate (81 %) than did demineralized allografts alone (94%), in combination with xenografts (83%), or in combination with tricalcium phosphate (94%) (log rank: $P < .0001$; Wilcoxon: $P < .0001$).

Life-table analyses were used to compare simultaneous and delayed implant placement in allografts. The 5-year cumulative survival rate for simultaneous implant placement in allografts (demineralized bone) was 94%, compared to 84% for implants delayed 4 to 8 months, and 97% for implants placed more than 8 months after graft placement. There was a significant difference among these three groups (log rank: $P < .006$; Wilcoxon: $P < .007$).

Xenografts

Xenografts (anorganic bovine bone) were used alone or in combination with other materials. The sample size for xenografts used alone for sinus grafting was too small to be analyzed. Implant results for xenograft combinations appear in Table 19-2.

Alloplasts

Life-table analysis was also performed on the results of implants placed in sinuses grafted with alloplast. The alloplasts used were porous hydroxyapatite (80%) or dense hydroxyapatite (20%), some of which have been labeled *resorbable hydroxyapatite* by the manufacturer. Tricalcium phosphate was another alloplast used in combination with other materials. The cumulative success rate was 98% for pure alloplasts; 98% for combination of alloplast and xenograft; 90 % for alloplast plus allograft; 80% for alloplast plus xenograft; 100% for tricalcium phosphate with autograft and allograft; and 99% for tricalcium phosphate with allograft.

1

Prosthetic analysis

Life-table analyses were performed to compare implant survival under removable prostheses, fixed prostheses, fixed prostheses with cantilevers, and fixed prostheses in relation to opposing prostheses (fixed versus removable). It was felt by the attendees of the conference, however, that the heterogeneity of techniques and clinical situations prevented a reasonable interpretation of the data; therefore, prosthodontic data were not presented.

Failure analysis

A committee was formed to study sinus graft and implant failures. Of the 2,997 implants analyzed, 229 were reported to have failed. Using radiographic and chi-square analyses, outcome determinants were examined for implants failing after 3 years. Two hundred variables were reviewed.

Outcome determinants

Residual bone height. Twenty implants of those in place for 3 years or more were lost. Of the 20 lost, 13 were initially placed in residual bone with a height of 4 mm or less, and seven in 4 to 8 mm. None of the implants placed in bone measuring 8 mm or more were reported lost. These differences were not statistically significant ($P = .12$).

Implant surface. Three hundred twenty implants were analyzed for their implant surface: 174 implants with a smooth titanium surface, 61 implants coated with titanium plasma-spray, and 85 coated with a hydroxyapatite. Fifteen (8.6%) of the smooth titanium implants were reported lost before the follow-up panoramic radiograph was taken; six (9.8%) of the titanium plasmasprayed implants and none of the hydroxyapatite-coated implants were lost. This result was statistically significant ($P < .02$).

Smoking. Of the 320 implants placed, 62 were in patients who were current smokers and 258 were in patients who denied tobacco use. Eight implants (13 %) in the smokers group were lost; only 13 (5%) were lost in the nonsmokers group ($P < .05$).

Graft height. Over 3 years, the combination of an autograft (intraoral bone) and an alloplast (hydroxyapatite) showed the least change in graft height among the various graft materials with a mean bone loss of 0.79 mm. The greatest loss in graft height (2.09 mm) occurred with demineralized freeze-dried bone (Table 19-8).

The mean magnification of the panoramic radiographs used in tracking graft height was 24.5% $\pm$ 1.23%. The minimum magnification was 21.1 % and the maximum was 30.1 %.

Outcome determinant results

This survey included a list of suspected determinants of implant failure. Each practitioner was to select those factors believed to have contributed to failure and identify the primary factor. Participants were then asked to categorize the failure as a surgical failure, a prosthetic failure, both, or a failure of unknown origin. Of the

Table 19-8 Grafting material and graft height

Graft material	n	Bone loss (mm) (mean I SE)
Combination of autograft (intraoral) and alloplast	42	- 0.79 IO.61
Combination of chin bone and alloplast	23	- 0.88 I 0.31
Alloplast (hydroxyapatite)	37	- 0.91 I 0.25
Chin bone	10	- 0.98 I 0.81
Combination of allograft and xenograft	57	- 1.40 I 0.48
Combination of hip bone and alloplast	43	- 1.63 I 0.46
Combination of allograft and alloplast	15	- 1.64 I 0.45
Hip bone	82	- 1.76 I 0.35
Allograft (demineralized freeze-dried bone)	40	- 2.09 I 0.58

229 failures identified in the database, only 164 were included in the final survey results. Exclusion resulted when patients were lost to follow-up, when patients lacked radiographs at or beyond failure, or when clinicians did not return the failure surveys, despite completion of entry records.

In most instances, doctors identified many outcome determinants. The most common ones were poor initial fixation, infection, a poor provisional prosthesis, and smoking.

Most frequently, the failure was not discovered until exposure of the implant was carried out; therefore, specific reasons for the lack of osseointegration were speculative. Of the 164 failures in this survey, 98 occurred either before or at stage 2 uncovering. One finding that correlated with loss of the implants was occlusal trauma from the provisional prosthesis, which occurred both in partially as well as completely edentulous patients.

Traumatic occlusion from the final restoration was identified as a cause of failure. The type of occlusal trauma was not identified; bruxism, however, was considered to be a significant contributor to osseointegration failure.

Chi-square failure analysis

To statistically analyze failure rates in the various sample groups, a Mantel Haesbel chi-square test was used on an effective sample size of 1,514 implants, all in function for 3 years or more. The chi-square test establishes statistical differences by deriving expected failure frequency versus observed frequency in the various test samples.

Various grafting materials and surgical methods were analyzed in this manner. These analyses focused on the choice of grafting material and the timing of implant placement relative to graft placement. Is there a difference in success based on (1) the material used for bone grafting and (2) the timing of implant placement?

Material used

Eleven materials were compared for definitive patterns of behavior. A test for biomaterials versus implant survival yielded a chi-square value of 92.5 and a *P* value of .001, indicating highly significant differences among biomaterials. Table 19-9 reports failing implants for each of 11 types of graft materials and material combinations and compares them numerically with surviving (healthy) implants in the same milieu, both at 3 years.

For the alloplast-alone group, the observed frequency of failure was 6%. The alloplast, alloplast/ xenograft, and alloplast/autograft combinations all had much lower than expected failure rates. Of 177 implants in which the autograft/alloplast combination was used, the actual failure rate was 14%. Alloplasts did better than expected in all groups, whether used alone or in combination.

The next most significant finding was for allografts. Pure allografts had 22 % observed failures and the alloplast/autograft combination had 36% failures. In contrast to the alloplast, the allograft performed relatively poorly, both on its own and in combinations. The alloplast/autograft/alloplast group showed 8 % failure and the allograft/alloplast group 12%, which was better than expected. The use of alloplast improved the results of allograft combined with autograft.

Table 19-9 Grafting materials and implant survival

Materials	Healthy implants	Failed implants	Total
Alloplast	116 (94%)	7 (6%)	123
Alloplast/Xenograft	121 (98%)	3 (2%)	124
Allograft	105 (78%)	30 (22%)	135
Allograft/Xenograft	41 (64%)	23 (36%)	64
Allograft/ Alloplast	210 (88%)	29 (12%)	239
Autograft	301 (83%)	62 (17%)	363
Autograft/Xenograft	6 (46%)	7 (54%)	13
Autograft/ Alloplast	152 (86%)	25 (14%)	177
Autograft/Allograft	30 (64%)	17 (36%)	47
Autograft/Allograft/Xenograft	35 (85%)	6 (15%)	41
Autograft/ Allograft/ Alloplast	155 (92%)	14 (8%)	169
Total	1272	223	1495

The xenografts (anorganic calf bone) did not perform like the alloplasts (nonresorbable hydroxyapatite), nor did the xenografts perform equally with allograft or with alloplast; they performed relatively unfavorably. The allograft/xenograft group had 35% failures, in contrast with the alloplast/xenograft group, which had 2%. These latter two combinations then provided an indirect measure of alloplast efficacy, because they both contained xenograft. When allograft was used in combination with xenograft, the failure rate was significantly higher than when the alloplast was used with xenograft.

The most frequently used grafting material was autograft, either alone or in combination. The harvest sites for the graft did not differ statistically; these included ilium, tibia, maxillofacial bone, and calvarium. The form of autograft was either particulate or block, but the autograft block was commonly expanded with particulate additions of autograft, allograft, alloplast, or xenograft. Autograft used alone (all sources and all forms) included 363 implants with 17% failures. The autograft/allograft combination experienced 36% failures. In contrast, the autograft/alloplast combination had a failure rate of only 14%, and the autograft/alloplast/allograft combination had a failure rate of 8%.

In general, the autograft group did better with alloplast added to it and worse with allograft. That is, allograft appeared to inhibit autograft success, whereas alloplast seemed to enhance it. Remarkably autograft, when used alone, did not fare as well as alloplast in the overall results.

Simultaneous versus delayed implant placement

The survival of implants placed simultaneously with a solid bone graft was compared with that of those placed 6 to 9 months afterward. The difference between these groups was not statistically significant. Regarding graft form, there was no statistically significant difference between particulate and block. When all autografts, regardless of form, were examined, however, there was a higher success rate with the delayed technique. This difference was statistically significant (chisquare = 4.3, $P = .037$).

Are the findings regarding delayed and simultaneous implants similar for nonautograft cases? Should the practitioner use a delayed approach with nonbioactive materials such as hydroxyapatite, or can an immediate approach be used just as well as is found in the various autograft situations? The chi-square analysis was used to test simultaneous and delayed techniques with various grafting materials. There were no significant differences between the delayed and simultaneous techniques in any of these groups.

Overall, then, the only grafts displaying a significant difference were in the pure autograft group. Regardless of harvest sites, they did better with the delayed approach than with the simultaneous approach (chi-square significance).

Limitations of the Analyses

The conference used implant survival rather than graft survival as the best measure of graft success because the implant data were available. Unfortunately, because of the retrospective nature of this project, panoramic views were inconsistent in quality. Variable magnification of the pantomographs was also a problem. Pantomographs were often not available at the critical follow-up times. Only a small number of the cases yielded quality preoperative, immediately postoperative, and long-term postoperative views of the grafts. The lack of adequate radiographic evaluation significantly limited the conclusions that could be drawn from this conference.

There are some false-positive and false-negative "successes" when implant survival is used as the primary measure. The residual bone, no matter how deficient, may be adequate to maintain an implant in function, irrespective of the loss of graft material. This introduced a false-positive result. It is not known in such cases whether the grafted or residual bone secured the implant.

A false-negative result occurs in instances where integration did not occur. This may have occurred with or without the bone graft. The incidence of implant loss in the posterior maxilla is generally at least 15%, independent of grafting.

Many cases were knowingly left out of the data pool. Cases where implants were never placed because of graft failure were not included. Moreover, most practitioners had instances where, due to a technical factor such as a membrane tear, the sinus graft was aborted.

The incidence of sinus graft failure then is undoubtedly higher than that emanating from the data of this conference.

Workshops

The participants of the conference were assigned, according to their expertise, to six workshops that focused on the following issues regarding the sinus graft:

- I. Indications and Contraindications
- II. Materials (Sections 1 and 2)
- III. Failure Analysis
- IV. Immediate Versus Delayed Approach
- V. Prosthetic Considerations
- VI. Nomenclature and Overall Conclusions

Their responses were to be based on the statistical analysis of submitted sinus graft cases (only well-documented cases loaded for 3 years or more), the literature, and the cumulative experience of the conference participants. Workshop sections were also asked to identify

those areas in need of further research. If consensus could not be obtained on any topic or question, minority statements were to be recorded and included in the final reports.

Six workshop groups, after analyzing the conference data and background literature, issued consensus recommendations, subsequently reviewed in plenary session. The workshop then presented revised consensus statements to a closing plenary session, which voted on them as (1) approved, (2) disapproved, or (3) approved with a minority opinion.

Consensus Statements

Workshop I: Indications and Contraindications

Preamble (*majority opinion*)

Review of the evidence and data presented at this consensus conference does not provide sufficient scientific or quantitative information as a basis for determining the indications and contra indications for sinus grafting. The workshop's recommendations reflect the limited literature information and the cumulative experience of its participants.

(*Majority opinion*): The workshop believes that there are factors that are not absolute contraindications but that may modify the risk of the procedure. These are listed as *risk factors*.

Consensus statement 1: Indications (*majority opinion*)

1. Edentulous areas in the posterior maxilla with inadequate bone where endosseous dental implant placement is required for the long-range restorative treatment plan. The literature has shown that less than 8 to 10 mm of vertical height may not be adequate for long-term success of endosseous implants in the posterior maxilla. This finding may be modified by the horizontal width and bone quality.

Consensus statement 2: Indications (*majority opinion*)

A. Anatomic (*majority opinion*):

L Inadequate transverse dimension of the sinus
Factors affecting risk (*majority opinion*):

1. Septa (increased risk of membrane tearing)
2. Ostium in surgical site

B. Dento-occlusal (majority opinion):

1. Inadequate or excessive inter arch space
2. Inappropriate ridge relationship Factors affecting risk (majority opinion): 1. Abnormal occlusal forces (eg, bruxism)

Consensus statement 3: Factors affecting case selection (majority opinion)**A. Medical conditions that help establish contraindication for the sinus graft treatment (majority opinion):** 1. Severely limited life expectancy

2. Systemic factors that adversely affect the survival of the implant or the graft
3. Conditions and medications that would preclude placement of dental implants
4. Pregnancy
5. Uncontrolled diabetes mellitus

Risk factors that may proscribe sinus grafting (majority opinion):

1. Intranasal or inhaled topical steroid use
2. Maxillary radiation therapy

B. Pathologic conditions that affect the local health of the sinus and may prevent successful sinus grafting (majority opinion):

1. Chronic, septic sinus disease
2. Active, acute sinus disease
3. Unrepaired oroantral fistula

Risk factors that may proscribe sinus grafting (majority opinion):

1. Previous sinus surgery
2. Cysts or tumors of the sinus

C. Habits that may proscribe sinus grafting (majority opinion):

1. Cocaine dependency

Risk factors that may proscribe sinus grafting (majority opinion):

1. Tobacco smoking
2. Alcohol abuse
3. Habits or dependencies that affect patient compliance

D. General and local dental health problems that should be addressed as they relate to sinus grafting and may interfere with successful treatment (majority opinion):

1. Associated periapical pathosis
2. Untreated active periodontal disease

Workshop II (Sections 1 and 2): Materials**Preamble**

This report is based on published material, the experiences of the group, and the data presented at this conference. A successful sinus graft must include:

- . Maintenance of maxillary sinus health.
- . Creation of bone within the sinus cavity.
- . Implant stability.
- Maintenance of sufficient bone around the implant for continued implant function.

Consensus statement 1: Autogenous bone is appropriate for sinus grafting

Basis for consensus statement:

1. Life-table analyses on more than 600 implants from 20 surgeons, with 91 % 5-year survival.
2. When the residual ridge is severely atrophic, an autogenous bone graft will provide a predictable result.
3. When the bone is moderately or mildly atrophic, autogenous bone is acceptable as a sinus-grafting material.
4. The safety and efficacy of autogenous bone for sinus grafting has been demonstrated.
5. These statements derived from conference data are confirmed by published reports in the refereed literature [see pages 225 to 227].

Autogenous bone is a clinically effective bone-inductive material. This statement is based on the experiences of the workshop participants.

Consensus statement 2

Allografts, alloplasts, and xenografts alone, or in combination with each other, based on the workshop participants' experience and the data collected at this conference, may be effective as a graft material in selected clinical situations. There are limited published data to make a statement about their use in severely atrophic situations (majority opinion).

Published data are too limited to make a statement about the use of these materials as a sinus grafting material for general use (minority opinion).

General statement: The consensus of the group is that the combination of autogenous bone and either allograft, alloplast, or xenograft, can be effective as a sinus grafting material (unanimous).

Basis for consensus statement: .

1. Data presented at this conference
2. Published literature
3. Experience of workshop participants

Questions:

1. What forms of autogenous grafts minimize the time from grafting to restoration?
2. Are new studies needed on the allograft used as a sinus material?
3. As the size of the defect increases, is a greater proportion of autograft needed?

Definition of success:

1. Success must consider the patient's function.
2. The case is a success as long as the prosthesis is continually functional and esthetic, regardless of individual implant losses.

Further information is needed from controlled clinical trials comparing materials and their combinations in different clinical situations. Future-comparative studies of graft materials must be controlled for the following (*majority opinion*):

1. Residual host bone height and width at the site of each planned implant site
2. Height of graft at surgery and at follow-ups
3. Volume of graft placed at surgery
4. Strict exclusion and inclusion criteria (eg, smoking, diabetes, ridge width, implant surface, implant shape, implant length, bone metabolism medications, flap design, surgical technique for tears, lateral wall barriers, healing time, loading, and final prosthesis design)
5. Defined outcome evaluation parameters (clinical, radiologic, and histologic): survival, pain, mobility, probing depth, and radiographic bone loss (graft and implant)

What are the anatomic and procedural factors that affect graft selection and clinical outcome?

Residual bone volume and quality: Residual bone height may affect clinical outcome. Data on residual bone and implant survival suggest that residual height influences implant survival rates; there is greater success with more bone. The relevance of graft material in this regard was not addressed. An article by Jensen⁷ supported this, but one by Hurzeler⁸ did not. Most studies have not addressed this question. Residual host bone height should be a focus of future studies (*majority opinion*).

Residual host bone height may affect graft material selection (*majority opinion*).

There are currently insufficient published data to warrant this statement (*minority opinion*).

For the workshop participants, bone volume and quality are currently difficult to quantify without the use of invasive means (histology) and as such cannot be shown to affect graft material selection. A sufficient

body of published literature does not exist to evaluate these parameters. They should be evaluated in future studies (*majority opinion*).

The workshop participants expressed the following OpInIOs:

1. The extent of the remaining dentition may influence graft selection (*majority opinion*).
2. Clinical outcome is influenced by the prosthetic design (*majority opinion*).
3. A lateral approach is the conventional one to sinus grafting. Not enough evidence exists to evaluate the transalveolar approach and its influence on graft selection or clinical outcome (*majority opinion*).
4. In the event that a minor tear occurs in the membrane, no change in graft selection is warranted (*majority opinion*).
5. In the event of a large, unrepairable tear in the membrane, a block graft might be used rather than a particulate one (*minority opinion*).
6. Prophylactic antibiotic coverage directed toward the antral flora is recommended, but it does not relate to graft selection. It may influence the clinical outcomes by influencing the incidence of infection (*majority opinion*).
7. No consensus on barrier use was found, and the influence on clinical outcome is not known. A study comparing Guidor with polytetrafluoroethylene revealed no difference in clinical healing or histologically at the bone-soft tissue interface⁹ (*majority opinion*).
8. Graft selection influences healing time and, in turn, clinical outcome¹⁰⁻¹² (*majority opinion*).

Workshop III: Failure Analysis

Consensus statement 1: Definition of failure

1. An individual implant is clinically mobile.
2. Peri-implant radiolucency is present.
3. The implant or graft is painful or infected.
4. The implant has significant ongoing bone loss cervically or apically.
5. The implant cannot be loaded.

These impressions are based on the failure data reported on by individual clinicians (failure analysis forms). Data forms were returned for 166 of the 229 failures reported out of 2,739 implants considered in the analysis.

Consensus statement 2: Failure considerations

Anatomic (data-based). Simultaneous implant and graft placement in sinuses with less than 5 mm of residual

bone height appear to yield a greater number of implant losses than those with more bone. However, the influence of other host factors is thought possible because the loss of the implants was clustered in patients. The failure data do not show any obvious difference between implant placement in premolar and molar locations. From the current presentation of the failure data, we cannot compare it to overall success rates in patients with less than 5 mm of residual bone.

Clinical impression. In addition, other anatomic factors that may influence success are number, location and size of septae and the severely atrophic maxilla with compromised surgical access via the lateral approach. Previous multiple surgical procedures may be related to an increased chance of failure.

Technical complications. An unrepaired tear in the sinus membrane may be associated with implant or graft failure. Failure data indicated that many implants were lost in patients with unrepaired sinus membrane tears. Inadequate graft placement leads to voids at implant sites and may affect sinus implant success. Poor fixation of implants and/or graft at the time of placement are additional factors and could affect sinus implant success.

Materials. The failure data as presented do not show any significant correlation between success and graft material.

Infections. Bone graft sinus infections were the cause of implant failure. The cause of the infection was unreported.

Prosthesis loading. Fifty-seven of the 166 failures were reported to be related to prosthetic factors. Factors that may be related could include bruxism, trauma from a provisional appliance, trauma from a final prosthesis, traumatic occlusion, and poor prosthetic design.

Patient selection. Because implant failures were clustered in various patients, we felt that this category should be included in this report. Outcome determinants are smoking, alcohol abuse, medical conditions, drug therapy, hygiene, and maintenance.

Summary. The data from the failure analysis forms are inadequate to permit ranking of the efficacy of the different sinus grafting procedures. All procedures reported on were highly successful. Analysis was limited by a lack of complete information on the failed implants and the relationship of that information to success. The data were inconclusive as far as implant surface coating is concerned.

Conclusion

This workshop committee recommends that, because of the lack of data, a prospective study be initiated using specific inclusion and exclusion criteria and specific outcome measures. Included in the outcome measures are the following criteria for success:

1. Individual implants in the grafted site are immobile.
2. No peri-implant radiolucency is present.
3. The implant and graft are without pain or infection.
4. The implant may have initial bone loss in the first year and no significant bone loss each year at the cervical or apical aspect of the implant.
5. The implant is prosthetically loaded.
6. The graft has no progressive bone loss after initial consolidation.

Some implants may fall between these criteria for success and failure. These implants are considered surviving until they meet the criteria for either success or failure.

Some dependent variables that should be considered for study:

- . Materials
- . Implant surface/type
- . Prosthetic design
- . Immediate versus delayed implant placement
- . Anatomic considerations
- . Surgical considerations

Workshop IV: Immediate Versus Delayed Approach

Consensus statement 1

The available literature, the data presented at this conference, and the clinical experience of the participants suggest that both immediate and delayed implant placement techniques using both autogenous and nonautogenous graft materials can be clinically efficacious in properly selected cases.

The present literature does not provide sufficient data to definitively indicate immediate or delayed implant placement.

1a. Anatomic considerations:

Based on the clinical experience of the participants, anatomic considerations that are clinically favorable for simultaneous implant placement include:

1. Osseous structure of sufficient quality and quantity to provide for primary stabilization of implants.
2. Physiologically adequate osseous bed for graft healing.

3. Alveolar and jaw relationship compatible with functional and esthetic restoration.

Based on the clinical experience of the participants, a delayed approach may be favored (considered or selected) when there is:

1. Insufficient bone quantity and/or quality for implant stabilization.
2. Extensive maxillary sinus pneumatization.
3. A compromised osseous bed.
4. Extensive alveolar lateral and/or vertical deficiency.

lb. Graft materials:

Considering the present data available, this issue is outside the consideration of immediate versus delayed implant placement.

lc. Prosthetic loading:

The committee could not make a statement on prosthetic loading as it relates to immediate versus delayed implant placement, except to recommend the principles established for bone density, regardless of the area of the mouth considered.

ld. Other considerations:

Advantages of immediate implant placement:

- . Patient convenience (decreased number of surgeries)

Potential advantages of delayed implant placement:

- . Less risk of graft and implant loss
- . Ability to evaluate the maturation of the graft prior to implant placement
- . Ability to place additional graft material as needed

le. Patient selection:

Known risk factors may favor delayed implant placement.

2. Future prospective studies:

- . Identify the quantity and quality of residual bone necessary for immediate implant placement
 - Evaluate particulate versus block autograft for immediate versus delayed placement . Evaluate free-standing versus splinted molars . Study variable three-dimensional configuration of the sinus and its impact on the decision of immediate versus delayed implant placement

Workshop V: Prosthetic Considerations

Consensus question 1: Do implant design and surface characteristics affect the therapeutic outcomes of sinus augmentation procedures?

The posterior maxilla has unique factors relative to stress:

- . Increased occlusal forces relative to the anterior dentition
- . Decrease in bone density
- . Potential increase in buccal-offset load
- . More often opposing natural dentition or tooth- or implant-supported fixed partial dentures

There is a need to provide sufficient evidence to conclude whether any specific implant design or surface will affect the clinical outcome. These are specific design and surface features that the prosthodontic section believes must be controlled during the data analysis in order to derive useful conclusions.

I. Implant design

A. Implant geometry

1. Threaded
2. Press-fit
 - a. Cylinders
 - b. Plateaus

B. Implant size

1. Length
2. Diameter

II. Surface characteristics

A. Titanium

1. Etched
2. Machined
3. Air-abraded
4. Plasma-sprayed
5. Porous coated surface
6. Other

B. Calcium phosphate (hydroxyapatite)

1. Various coating methods

VOTE: Unanimous

Consensus question 2: What effects do prosthetic designs and loading have on the success or failure of the sinus augmentation procedures?

From the limited data presently available on prosthetic reconstruction with implants placed in sinus grafts, it would appear that there are no unique prosthodontic recommendations or restrictions specific to this area of concern. However, recognizing the concerns noted in restoring the posterior maxillary region, the prosthodontic section recommends the following procedures:

1. Controlled axial loading
2. Special care with provisional restorations during the healing of implants
 3. Confirmation of individual implant stability prior to placement of the definitive restoration

There is a need to provide sufficient evidence to conclude whether any specific prosthesis designs or loading factors will affect the clinical outcome. These are the confounding variables that the prosthodontic section believes must be controlled during the data analysis in order to derive useful conclusions.

I. Prosthesis design

- A. Geometry of abutment connection
- B. Abutment
 1. Material
 2. Design
- C. Cementable
 1. Definitive versus provisional
- D. Screw-retained
 1. Quantification of preload torque
 2. Screw material and design
- E. Fixed-single-tooth
 1. Metal-ceramic
 2. Metal
 3. All-ceramic
 4. Metal-composite resin
- F. Fixed-partially edentulous
 1. Metal-ceramic
 2. Metal
 3. Hybrid (metal-acrylic resin)
 4. Milled subframe superstructure
 - a. Metal
 - b. Metal-ceramic
 - c. Hybrid
 5. Freestanding or connected to natural teeth
 - a. Type of connector
- G. Fixed-completely edentulous
 1. Metal-ceramic
 2. Hybrid (metal-acrylic resin)
- H. Fixed-removable-partially edentulous
 1. Milled subframe superstructure
 - a. Metal-acrylic resin
 - b. Metal-ceramic
 2. Partial over denture
- I. Fixed-removable-completely edentulous
 1. Milled subframe superstructure
 - a. Metal-acrylic resin
 - b. Metal-ceramic
- J. Overdenture
 1. Attachment mechanism
 - a. Prosthesis movement

2. Are implants splinted together
3. Materials

II. Stress factors

- A. Age
- B. Sex
- C. Parafunctional habits
- D. Number and position of remaining teeth
- E. Disease status of the remaining teeth
- F. Opposing occlusion
- G. Bone density
- H. Bone quantity
- I. Masticatory musculature dynamics
- J. Occlusal load and direction on each prosthetic tooth
- K. Cantilevers
- L. Number of implants
- M. Implant design and dimensions
- N. Implant position in the arch
 1. Implants in line
 2. Anteroposterior distance
- O. Buccolingual offset
- P. Implant angulation
 1. Vertical versus angular forces
- Q. Cuspal inclination
- R. Buccolingual dimensions of prosthetic teeth
- S. Crown-implant ratio
- T. Materials
 1. Composite resin
 2. Acrylic resin
 3. Metal
 4. Metal-ceramic
 5. All-ceramic
- U. Crossbite relationship
- V. Maxillomandibular jaw relationship
- W. Dynamic occlusal scheme
- X. Immediate or progressive loading
- Y. Type of provisional prosthesis utilized during stage 1 healing

Note: Given the number of confounding variables listed, the prosthodontic section believes that it would be almost impossible to derive statistically significant data leading to relative risk indices from a retrospective study. Therefore, it is strongly recommended that prospective studies be designed with only one set of prosthetic variables to allow practical data collection.

Conclusions

The data that were gathered for review at this conference concerning implant-supported prosthesis success do not satisfy the scientific method. Therefore, the data collected cannot provide a correlation between implant and prosthesis survival.

VOTE: Unanimous

Workshop VI: Nomenclature and Overall Conclusions

This select committee voted unanimously to term the sinus procedure under consideration "sinus graft" rather than "sinus lift" or any of the many other terms appearing in the literature.

The body of data considered by conference participants was overwhelmingly retrospective; that is, the questions asked of participants were raised after the fact. As such, this conference did not preclude biases generally eliminated in randomized, controlled, prospective clinical trials. Such retrospective data are fraught with problems relating to discrepancies in selection criteria, operative conditions and techniques, and evaluation criteria:

1. Data are recorded differently and at differing time points.
2. Information is missing or incomplete.
3. Different assessment techniques are used.
4. Assessments are uncalibrated.
5. Clinical judgments (eg, about "failure") are already made.

The retrospective case series evaluated by this conference, however, include a significantly large number of subjects and procedures and represent most of the long-term data available. The conclusions drawn, then, become more reliable and relevant and of significant value until far more extensive and painstaking prospective trials are carried out.

At this conference, a number of clinicians reported 100% or nearly 100% success. These reports raised an issue of credibility in the minds of many. All such reports were included in the data, but the credibility issue did impact the drafting of consensus statements and the degree to which concrete recommendations could be made to the profession. For example, the primacy of allografts over autografts and the negative affect of allografts on material combinations, both reflected in the data, did not emanate as consensus statements. This is not to say that "98%" or "100%" is an impossible or unbelievable result per se. Doubt about such results is well grounded, however, because it is based on the collective and extensive clinical experience of the overwhelming majority of conference participants.

It is our feeling that the conclusions (consensus statements) derived by this conference, although limited, are of significant clinical relevance. The conference basically concluded that "the sinus graft works," but called for answers to the questions of "Why?" and "How?". Prospective clinical trials in this light are imperative. The six questions posed at the outset of this conference were largely answered.

The conference was unanimous in agreement that the sinus graft is an *efficacious* procedure. It concluded that, "The sinus graft is effective as an adjunctive procedure to be used for implant-supported restorative dentistry in the posterior maxilla." Accordingly, the sinus graft per se can no longer be considered an experimental procedure; its efficacy is based on a large database. "Sinus grafting is reconstructive bone graft surgery of the maxillofacial facial skeleton appropriate for functional rehabilitation of the upper jaw."

Indications and contraindications

The question of indications and contraindications must be explored more fully. However, it was generally agreed upon that there is some threshold of osseous deficiency for which a sinus graft is required to enable implants in that zone to be successful and that less than 8 mm of vertical bone in the posterior maxilla is a reasonable approximation of that deficiency.

Materials

The various materials used in the sinus graft *all* seemed to perform well, the allograft being the least successful. All graft materials used yielded at least 80% implant success for 3 to 5 years; this efficacy is comparable to the 85 % 5- to 12-year results for complete-arch implants placed in residual bone, that is, without a bone graft.³ Implants retained for more than 5 years, although few, continued to show a greater than 80% success rate.

Many other factors are involved in the use of autogenous bone, among them its source, form, and use. The conference participants reached a consensus on when to use iliac graft; it is generally reserved for highly resorbed ridges, ie, sites with a guarded prognosis. Allograft and alloplast are recommended for less resorbed ridges; their choice is a matter of surgical judgment. Unfortunately, when to make this choice is not clear from the data of this conference. The use of autogenous modalities, ie, mentum, ramus, tuberosity, ilium, tibia, or calvarium, is advocated in situations where there is compromised osseous structure to begin with, eg, a very thin antral floor. The level of autograft success may be biased by its preferential use in the more challenging cases, because allografts and alloplasts are chosen for the "easier" sites.

Failure analysis

The success rates for implants placed in grafts of different materials and material combinations were rather similar. Because of the multiple variables operating in these retrospective studies, it was impossible to state

with certainty that one material or technique was better than another. Many participants believed that autografts were the most efficacious and allografts the least. Allogeneic bone appeared to diminish effectiveness whenever added to another material. On paper, alloplasts had the most favorable results, even more favorable than autografts; however, this conclusion was not supported by statistically significant conference data.

Immediate versus delayed approach

There were no clear cut differences between simultaneous and delayed approaches.

Prosthetic considerations

No prosthodontic variables could be identified that were specific to sinus grafting cases. All prosthetic recommendations applied just as well to non-sinus grafting cases. Accordingly, prosthodontic outcome determinants could not be defined from the database or from committee discussions.

Summary

The major questions before this conference were answered, in large part, through the use of acceptable statistical methods and an arduous consensus process. The conclusions drawn were limited by the retrospective nature of the data. The doubts raised reveal the need for controlled prospective multicenter clinical trials.

Having 3,000 sinus graft cases from this conference, we know the limits of this retrospective data in the hierarchy of scientific evidence. These data were analyzed in statistical terms, but not at a high level of significance. The implant community, however, does not at present have anything better. This consensus conference at the least has established current indications for prospective clinical research on the sinus graft procedure.

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